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Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Houston-Galveston Navigation Channels, Texas Project

Navigation Channel Sedimentation Study, Phase 2 Plan Simulations

Jennifer N. Tate and Cassandra G. Ross

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Abstract: This report documents the results of several plan scenarios on the sedimentation behavior in the Houston-Galveston Ship Channel area. The U.S. Army Engineer District, Galveston, recently enlarged the Houston Ship Channel in depth and width. Preliminary evaluations of the enlarged channel indicate a higher than anticipated rate of deposition in the channel reach near Atkinson Island. A Coastal and Hydraulics Laboratory investigation (Tate and Berger 2006) was charged with determining if this higher deposition rate is a permanent feature or only a temporary issue. A preliminary study focused on the change in currents, as determined by the model, from the pre-enlarged channel to the new configuration and a sediment tracer analysis. The results of this study determined that the dredging should have been only about 20-30 percent higher than for the pre-enlarged channel. This implies that a large increase would be due to other considerations, such as dredged material resuspended from disposal areas and redepositing in the channel, channel dimension equilibration, or vessel impacts on the shoaling. This preliminary study used the sediment model in an unvalidated state for early results to aid planning. In addition to an unvalidated model, other limitations were that the sediment pathways and loadings were not modeled but assumed. A more general validated tool was needed to estimate the causes of the shoaling with the enlarged channel and suggest approaches to reduce the deposition rate. Knowing that there are many factors that contribute to sediment transport, the logical next step was to develop and validate the sediment model. With a validated sediment model, testing and decision making can be made while considering many factors simultaneously. In the validation process it was determined that vessel traffic was important in the deposition and resuspension of sediment. Vessel effects, therefore, are included in this model. The end result is a model that is capable of reproducing tides, circulation, salinity, and sediment transport in Galveston Bay. In addition to these properties, the model also includes the effects of vessel traffic on the sediment transport in the area (Tate et al 2008). Now that the validated sediment model is available, plan simulations can be performed to analyze the effects of various changes within the system.

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Preface

This report represents the findings of an investigation of the results of several plan conditions on the shoaling within the Houston Ship Channel and surrounding areas.

This investigation was conducted from October 2007 through June 2008 at the U.S. Army Engineer Research and Development Center (ERDC) by J.N. Tate and C.G. Ross of the Coastal and Hydraulics Laboratory (CHL). Funding was provided by the U.S. Army Engineer District, Galveston.

The work was performed under the general direction of Thomas W. Richardson, Director, CHL, B.A. Ebersole, Chief, Flood and Storm Protection Division, and Dr. Robert McAdory, Chief, Estuarine Engineering Branch, CHL.

At the time of publication of this report, COL Gary E. Johnston was Commander and Executive Director of ERDC, and Dr. James R. Houston was Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
knots	0.5144444	meters per second
microns	1.0 E-06	meters
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
pounds (force)	4.448222	newtons
slugs	14.59390	kilograms
square feet	0.09290304	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

1 Background

The U.S. Army Engineer District, Galveston (SWG), recently enlarged the Houston Ship Channel from a 40-ft depth by 400-ft width to a 45-ft depth by 530-ft width. Preliminary evaluations of the enlarged channel indicate a higher than anticipated rate of deposition, by a factor of about two, in the channel reach near Atkinson Island. A U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (CHL) investigation (Tate et al. 2006) was charged with determining if this higher deposition rate is a permanent feature or simply a temporary condition. The study focused on the change in currents, as determined by the model, from the 40- x 400-ft to the 45- x 530-ft condition. The model hydrodynamics had been validated by comparison to the field in previous studies (Berger et al. 1995a and 1995b). The sediment component of the model was used without a validation with field data, although some parameters were set based upon the field sediment data. Since the object of the sediment component was simply to determine the transport patterns of a sediment tracer applied over a given area, a validation was not necessary. The results of this study determined that the shoaling should have been only about 20-30 percent higher than for the 40- x 400-ft channel. This implies that the large increase in shoaling is due to other considerations, such as dredge disposal escape, channel dimension equilibration, or vessel impacts on the shoaling. However, this study made several assumptions about the sediment distribution, including the sediment transport preferred pathways and loadings. Knowing that there are many factors that contribute to sediment transport, the logical next step was to develop and validate the sediment model. With a validated model, predictions of shoaling can be made with more certainty.

The CHL then proceeded to develop a validated sediment model of the Houston-Galveston ship channels and surrounding shallows (Tate et al. 2008). Figure 1 shows the areas included in this modeling effort. The model validation was intended to determine the bed and sediment properties necessary to match field data and accurately reproduce the physical properties occurring within the system. Initial properties were based on analysis of field data and those parameters that contain uncertainty were varied to determine the values that best compare to the known field conditions during the validation period.

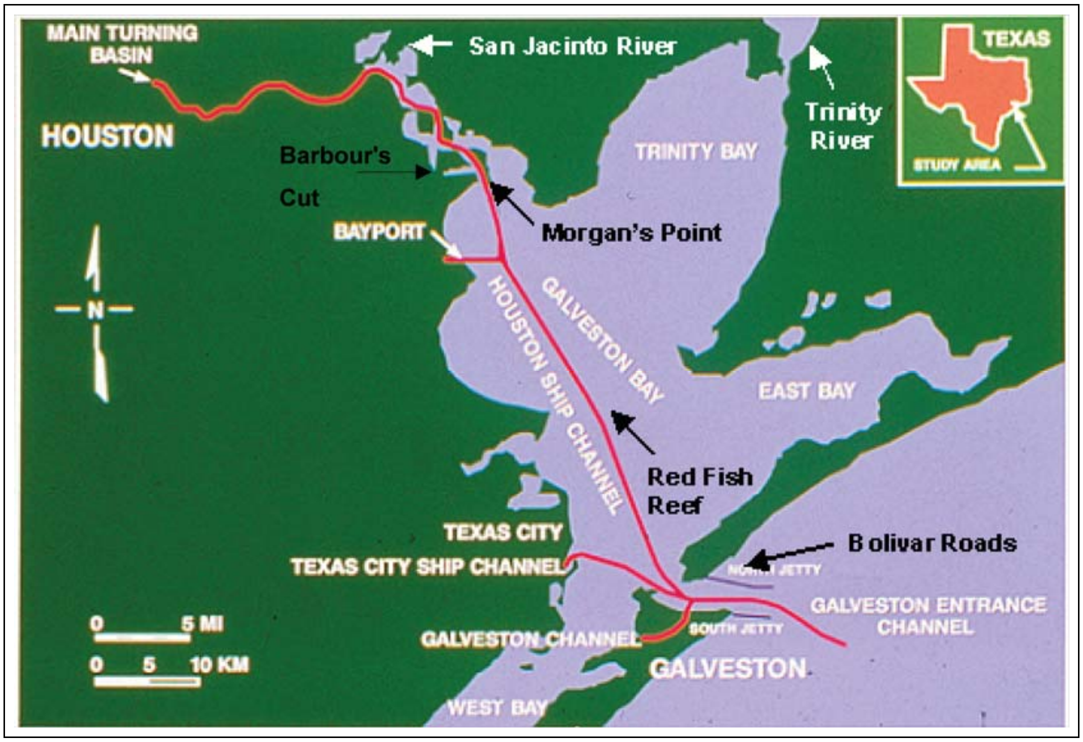

Figure 1. Houston-Galveston Navigation Channels location map.

The TABS-MDS based three dimensional (3D) hydrodynamic and salinity simulation was performed first to obtain the velocities, water depths, and salinity gradients used to drive the sediment runs without consideration of vessel traffic effects. The model included winds and currents for resuspending and transporting the sediment. The model was run to simulate two water years, a high flow and a low flow condition. Due to the Houston Ship Channel's large volume of vessel traffic and knowing that the vessel movement generates large shear stresses on the bed which affect the erosion and transport of sediment, a typical day of vessel traffic was simulated in a companion ADH based hydrodynamic model and repeated daily over the year long runs. These vessel effects from the ADH based model were then combined with the TABS-MDS based model results to obtain hydrodynamic and salinity results suitable for calculating sediment transport in the system. The sediment simulation was then run using bed characteristics taken from the field data analysis and the combined hydrodynamic and salinity results. The sediment inflow concentrations were based on rating curves generated from historic loads for the two major rivers entering the system, the Trinity River and the San Jacinto River. The results of these runs were analyzed for the magnitude and pattern of deposition along the channel and in the shallow areas, as well as for their agreement with suspended sediment samples. Historic dredging records and suspended sediment concentrations for the same period of the simulation were used for comparison. The results of the sediment model validation showed good agreement with the suspended sediment concentrations and the distribution of shoaling along the channel. The rate of shoaling in the channel and the overall volume of material being deposited were somewhat lower than that found in nature. Details of the sediment model validation as well as the ADH and TABS-MDS codes can be found in Tate et al. 2006 and 2008.

2 Enlarged Channel Simulations

The initial plan simulated with the validated sediment model was the enlarged channel condition. In this prototype enlarged channel, there has been an increase in shoaling beyond what was expected since this channel enlargement was implemented. By performing the simulations on the new channel dimensions, the changes in the shoaling due to the vessel traffic and hydrodynamics in the enlarged channel, as compared to the unimproved channel, can be determined.

Using the parameters determined during the sediment model validation, the enlarged (45- x 530-ft) channel was modeled for the same two water years. The results for the shoaling along the channel center indicate an increase of approximately 30 percent from the pre-enlarged channel condition. Figure 2 shows the model produced volume of deposited material along the channel center for both channel conditions. The modeled distribution rate of deposited material down the center of the channel remains fairly consistent for the two channel conditions, as seen in Figure 3. These data are normalized by the overall average because the purpose of this comparison is strictly to determine the pattern of shoaling distribution, not the magnitude as with Figure 2. There is an increase in deposition magnitude and rate upstream of Bayport due to the loads entering from the San Jacinto River and the increased trapping capability of the larger channel.

The vessel traffic along the channel prevents modeled sediment from depositing onto the bed just outside of the channel, especially in the upper reach along Atkinson Island. This is likely the cause for the increase in shoaling distribution upstream of Bayport when compared to the dredging records. Figure 4 shows the channel centerline deposition thickness for both channel dimensions with and without the inclusion of the vessel effects. This value is a thickness, not a volume as in Figure 2. Although the deposition thickness is less at times for the enlarged channel, the volume is greater for this channel due to the larger width.

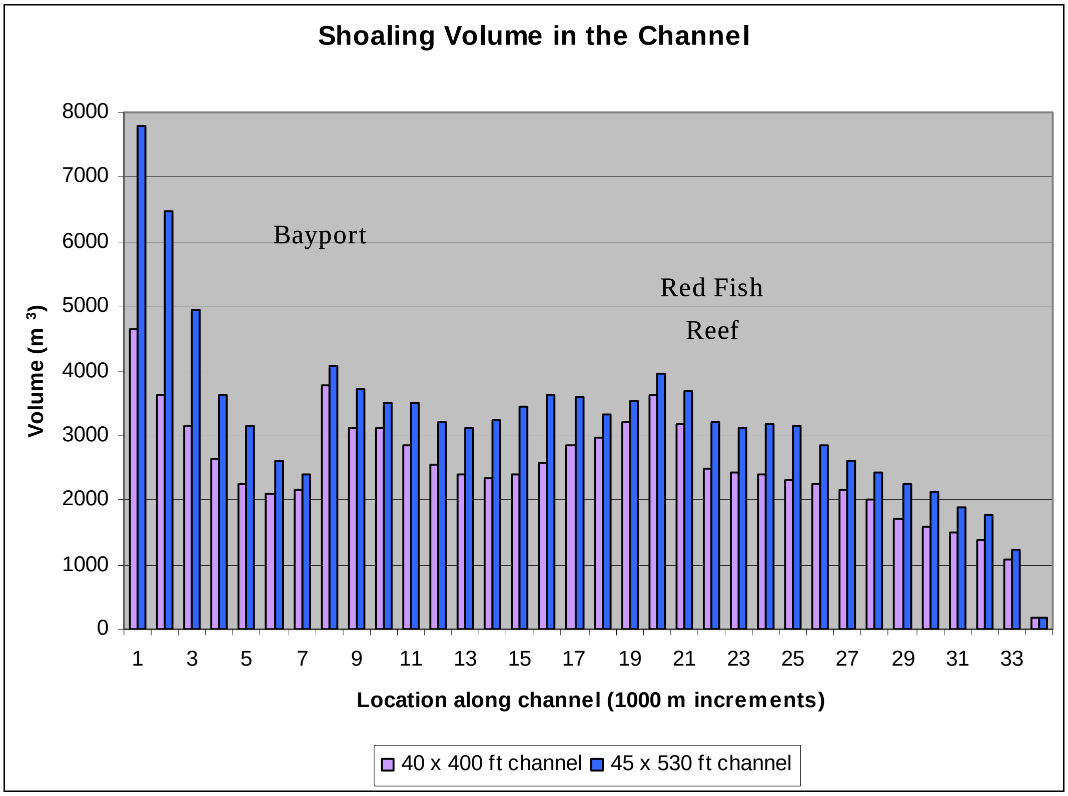

Figure 2. Modeled volume of deposited material in the channel for both channel conditions.

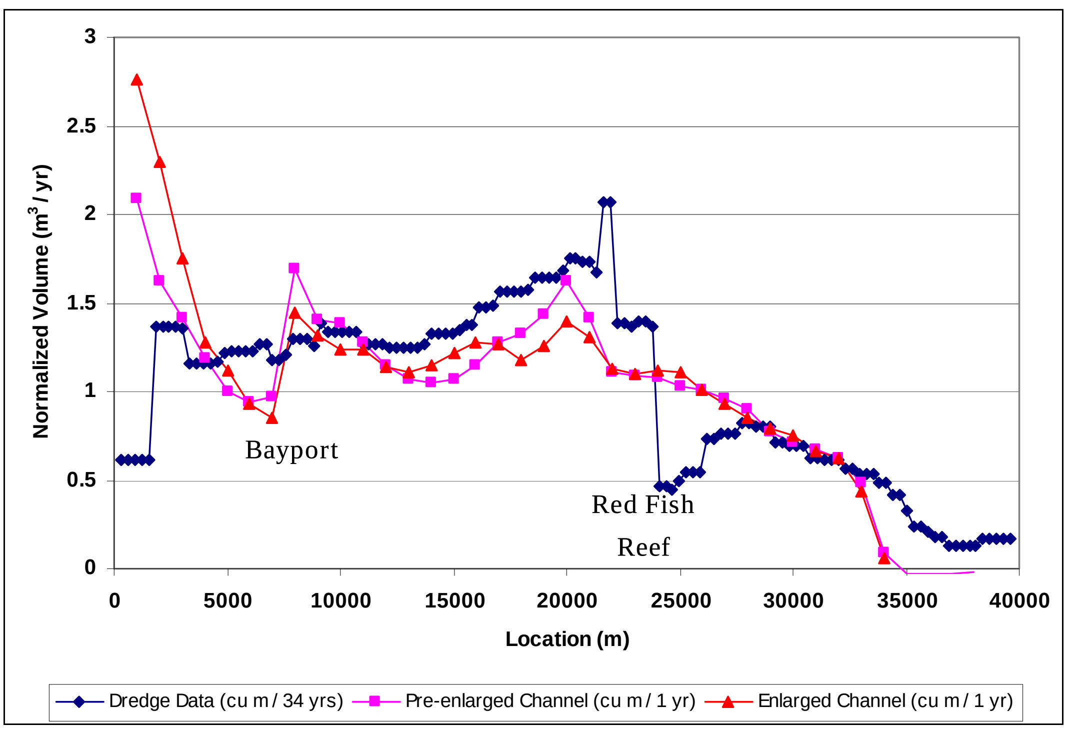

Figure 3. Normalized volumetric shoaling rate along the channel for the historical data and modeled results for both channel configurations.

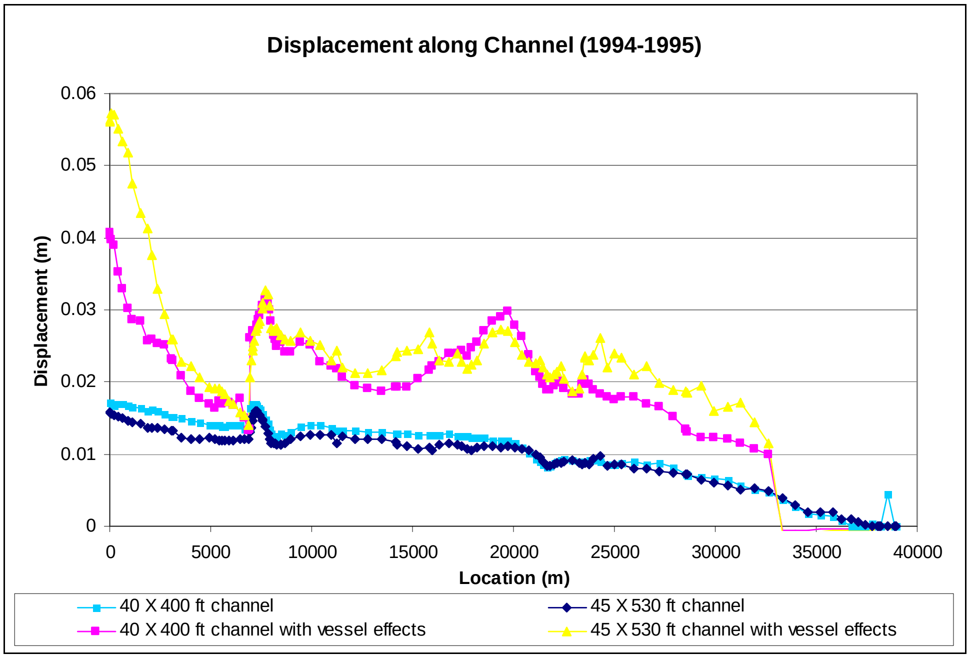

Figure 4. Modeled deposition with and without the inclusion of the vessel effects.

It is obvious that the inclusion of the vessels allows for more deposition in the channel. This occurrence is due to the shear stresses generated by the moving vessel being large enough to cause erosion of the bed and hinder deposition in the shallows outside of the channel. Now that the sediment remains in suspension longer and due to the velocity pattern around the vessel, the sediment travels toward the channel easily where it then deposits.

These simulations indicate that the enlarged channel will experience more deposition than did the previous channel. However, the initial indications were that the observed volumetric increase was on the order of two times greater. Model simulations have only been able to account for a 30 percent increase in the shoaling in the channel, indicating that this large increase is likely not a permanent feature of the enlarged channel or that it is caused by a phenomenon not captured by the sediment transport model.

3 Plan Simulations

Given the increased channel shoaling, evident in both the prototype and the modeling, several plans were developed for testing in the model as potential shoaling reduction measures. The SWG provided CHL with four plan alternatives to simulate in order to determine the effects each produces on the flow patters and shoaling in the area of the changes as well as in the channel itself. The base condition for all of these plans is the 45- X 530-ft channel dimension, which is the current field dimension of the channel. These plan alternatives are described as (see Figure 5):

a. Plan 1 – close the gap between placement area (PA) 14 and 15 in Atkinson Island. The northern four enclosed red areas, M1 – M4 in Figure 5, are included.

b. Plan 2 – include the dredge disposal sites, M5 – M8 on the east side of Atkinson Island. (M1 - M4 are already built and included in the model.) This includes all of the enclosed red areas shown in Figure 5.

c. Plan 3 – combine Plan 1 and Plan 2.

d. Plan 4 - determine the distance PA 14 should extend southward to reduce/eliminate the shoaling in the Bayport Flare.

The sediment model simulations require a hydrodynamic model simulation of the time period being modeled. In these cases, the simulation time consists of water year 1995 which begins October 1, 1994 and completes September 30, 1995. To accurately describe the hydrodynamics and salinity at the start of the simulation period, a 3-month "spin-up" is performed from July through September 1994. This allows any initial condition effects to be removed from the system before the analysis period begins. Simultaneously, vessel transport simulations are performed to determine the vessels' impacts on the shear stresses felt by the bed in order to include their effects in the shoaling estimates. Once the hydrodynamic and vessel simulations are complete, the sediment model can be run. The sediment model is driven by the hydrodynamics already computed. The shear stresses due to the vessel movement and those generated by the flow conditions and the winds are combined to determine the total shear stress on the bed. The erosion and deposition that occur in any system are dependent on the shear stress that the bed sediment requires for mobilization and the shear stresses that are applied on the bed. If the shear stress applied to the bed does not exceed that needed for the bed to erode, then no erosion will occur. All plan and base conditions were simulated in the same manner using the same boundary conditions and model characteristics.

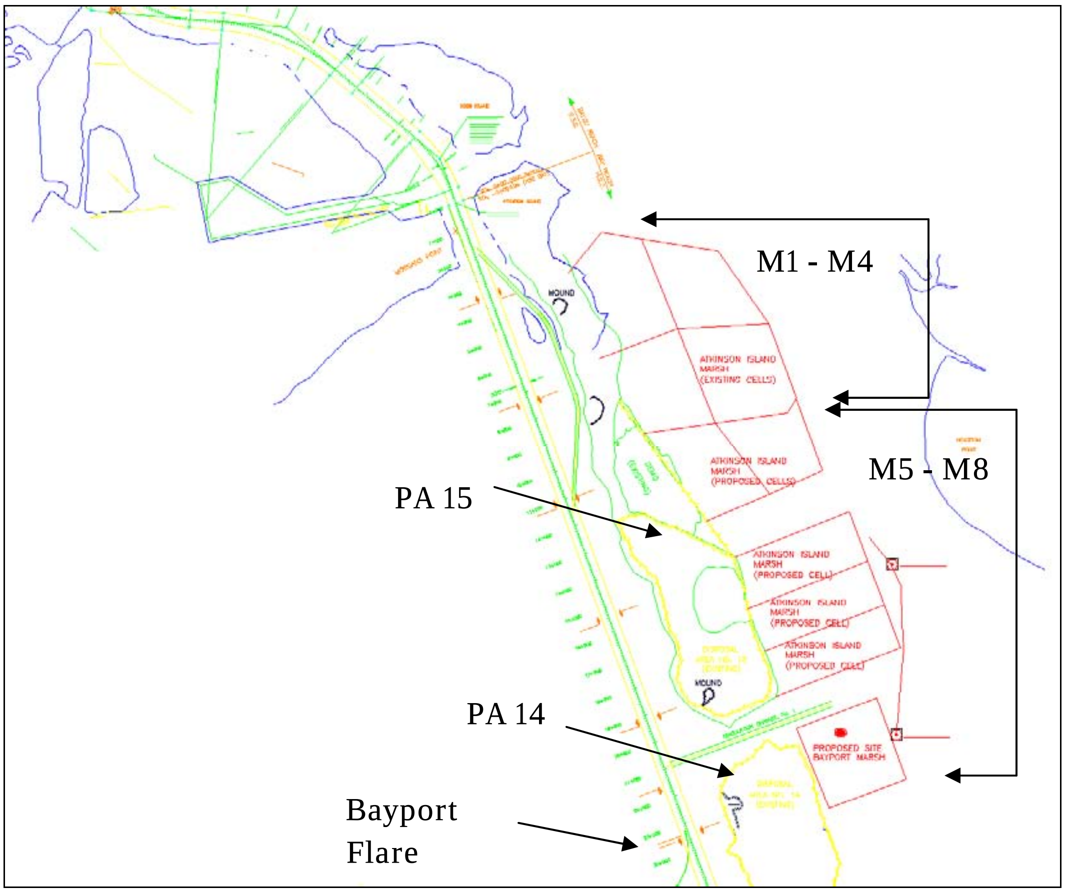

Figure 5. Plan alternative reference map.

Plan 4 required a preliminary analysis of the sediment fluxes across specific areas to be performed in order to determine the extension distances to test in the sediment model. This plan included two full model simulations. The sediment existing fluxes were calculated using the hydrodynamic and sediment results from the base condition simulations. Figure 6 shows the location of the flux calculations. Figure 7 shows the flux values for a time period about two months into the simulation. Included in this figure is a 100 point moving average trendline for each location. Since the data was analyzed every half hour, the moving average calculation will include just over two days of previous data to determine the average for the trendline. This moving average will show whether the dominant flow direction is flood (positive) or ebb (negative). If the sediment flux is negative, the sediment is flowing down the back side of Atkinson Island and has the possibility of entering the channel in the area of the Bayport Flare.

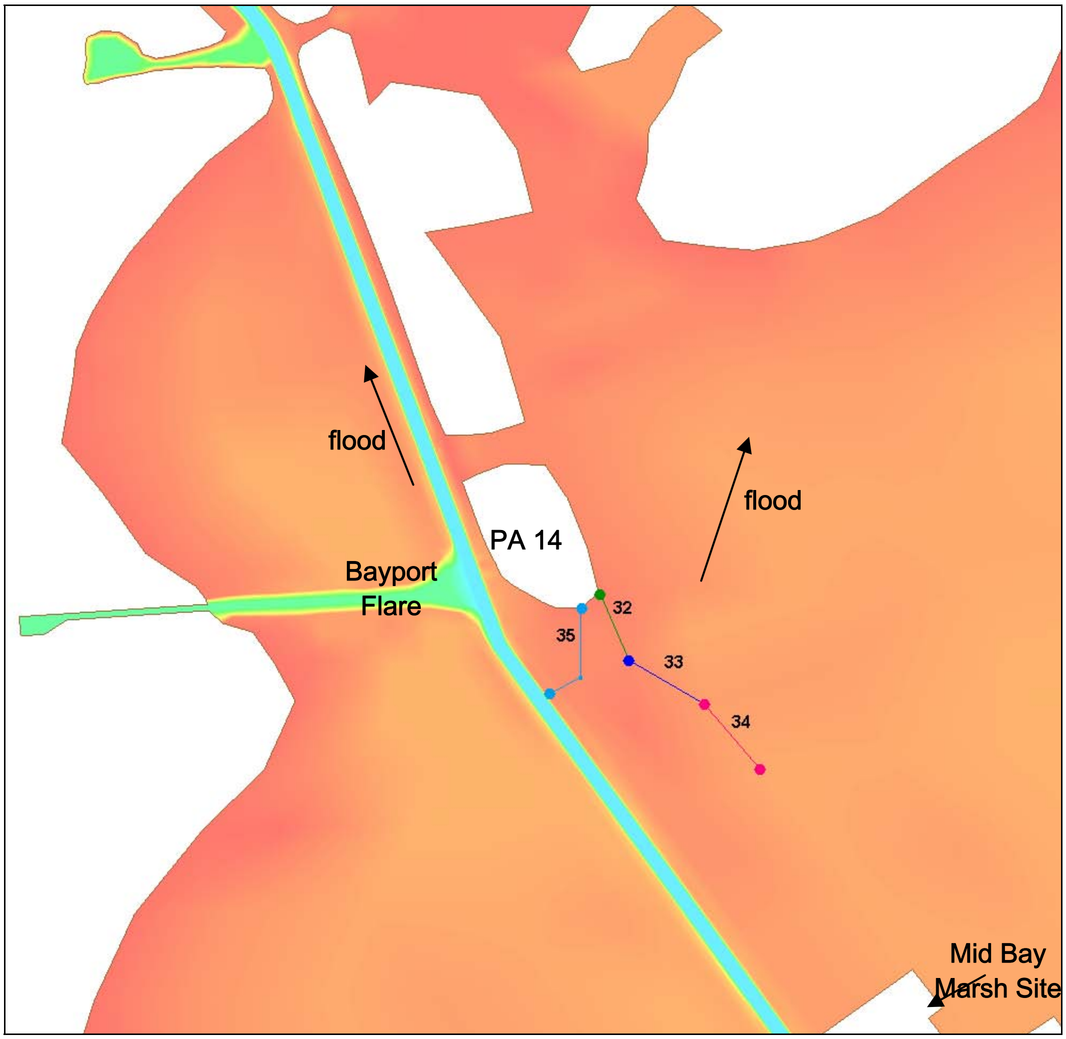

Figure 6. Location of sediment flux calculations.

Locations 34 and 35 show flood directed flows while locations 32 and 33 are dominated by ebb directed flow. These flow directions indicate that sediment traveling in the ebb direction at locations 32 and 33 are very likely to turn toward the flood direction as they reach location 35. Location 34, which is the furthest downstream location, i.e. closest to the Gulf of Mexico, indicates that flows are moving into the Trinity Bay area. The hydrodynamics in the eastern Trinity Bay are such that tidal flows move up through the center with circulation moving in the ebb direction along the bay boundaries. Therefore, the extension of PA 14 should not extend into the area of location 34 since that would trap sediment on the channel side of the island. The two extensions that will be tested will 1) extend to the southern end of location 32 and 2) extend to the southern end of location 33. Figure 8 shows these extensions along with the base condition and Table 1 gives the placement area lengths for each. The basic shape of PA 14 was maintained as the area was extended.

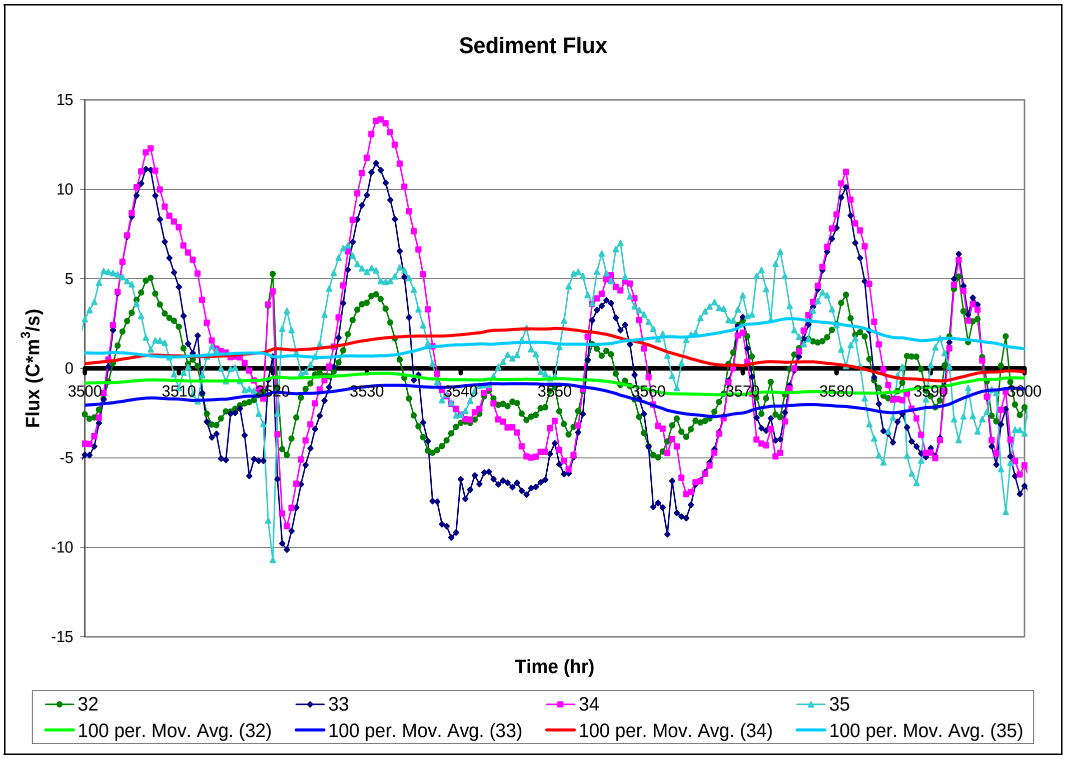

Figure 7. Sediment flux south of Atkinson Island.

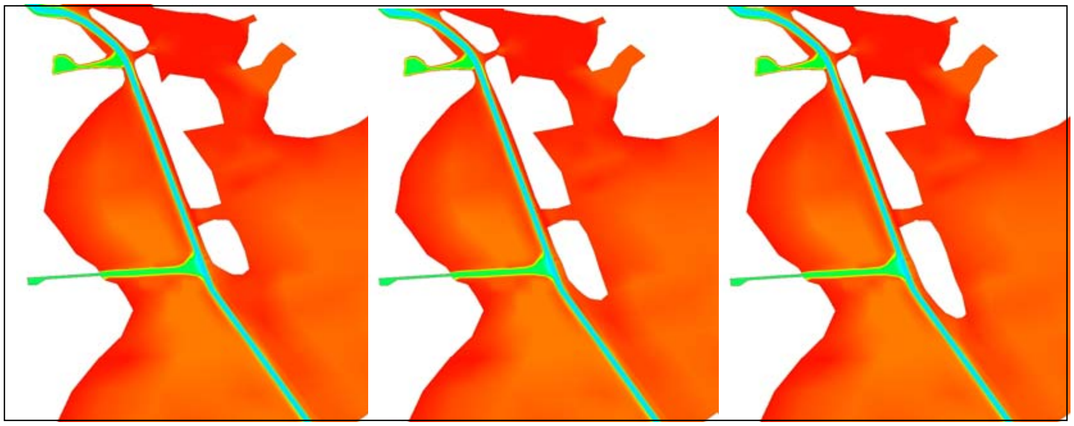

Figure 8. Base conditions and PA 14 extension 1 (center) and extension 2 (right).

Table 1. PA 14 lengths.

Plan	Length
Base	7510.8 ft
Extension 1	10730.2 ft
Extension 2	13069.8 ft

4 Plan Results

The first three plan conditions were modeled and the results compared to the base condition. The base condition consists of the Houston Ship Channel in the 45- x 530-ft dimensions after the last channel enlargement. The plan conditions were analyzed to determine the changes in the flow magnitudes in the areas of the proposed improvements and for the changes in sedimentation in these areas and the channel. Figures 9-12 show the bottom velocity magnitudes for the base and the three plans. These figures are at a time during a high ebb flow event early in the simulation, hour 2639.5, and contoured such that blue areas have a velocity of 0 ft/s and red areas 1 ft/s. At this time, flow in the channel is directed toward the Gulf of Mexico, referred to as downstream in this document, along Atkinson Island to the location of the Bayport flare, at which point the direction of the channel flows becomes upstream. Figures 13 - 16 are bottom velocities of the same form as the previous but at the completion of a high ebb flow immediately prior to the flow turning to the flood direction (hour 7749.5). This is a time of generally low flows in the system when the flows in the channel are directed upstream. Figures 17-20 show bottom velocities at hour 10709.5 near the completion of the year long simulation. This time is during a flood flow situation with large upstream directed flows in the channel. At this time there is a strong wind from the north-northeast influencing the flows, especially near the surface.

The changes in the hydrodynamics due to Plan 1 are focused in the vicinity of the gap between PA 14 and PA 15, which is filled in Plan 1. At the early timestep (2639.5 hr) there is an increased area of higher velocities along the eastern edge of Atkinson Island, now that the flow through the gap is removed. At hour 7749.5, the largest differences are along the eastern side of Atkinson Island near the filled gap. The final timestep shown, hour 10709.5, indicates affects on the direction of flows in the channel at the location of the removed gap as well as an area of increased flows around the southern tip of Atkinson Island.

Plan 2 includes dredge disposal sites at M5 - M8 while leaving the gap open between PA 14 and PA 15. Now that these areas are included in the model, the flows around the eastern side of Atkinson Island increase over the base more than Plan 1 due to the reduced flow area. It is visible in hours 2639.5 and 7749.5 that the inclusion of the southern-most disposal site pushes the flows further away from PA 14, reducing the flows on the eastern side of this placement area by effectively shadowing it from the ebb flows.

The changes in hydrodynamics due to Plan 3, which is a combination of Plan 1 and Plan 2, are very similar to the changes observed from Plan 2. At the early timestep, the increase in flows around the eastern side of Atkinson Island is still apparent, but the closure of the gap between PA 14 and PA 15 reduces the extent that these increased flows are felt into Trinity Bay from that seen in Plan 2. During the lower flow ebb event at hour 7749.5, the Plan 3 results are essentially identical to those from Plan 2 since there is little flow passing through the gap when it is open. At hour 10709.5, there is an increase in flows around the south-eastern side of PA 14. Although the flows through the gap in Plan 2 are reduced when they are cut off completely, as in Plan 3, the flows coming from Trinity Bay must all now join with those coming around the island, therefore, increasing the magnitude of the flows around the south-eastern tip of Atkinson Island.

Figures 21-28 show the bed displacement for the base and three plan conditions in the vicinity of the changes at six and twelve months of simulation. The difference in the magnitude of the bed displacement from the base condition for Plan 1 at six and twelve months is shown in Figures 29 and 30. These same images are shown for Plan 2 in Figures 31 and 32 and Plan 3 in Figures 33 and 34. All of these images are contoured between -0.01 m and +0.01 m. Reds (+0.01 m) indicate that the base condition is of a higher magnitude and blues (-0.01 m) indicate that the base has a lower value than the plan.

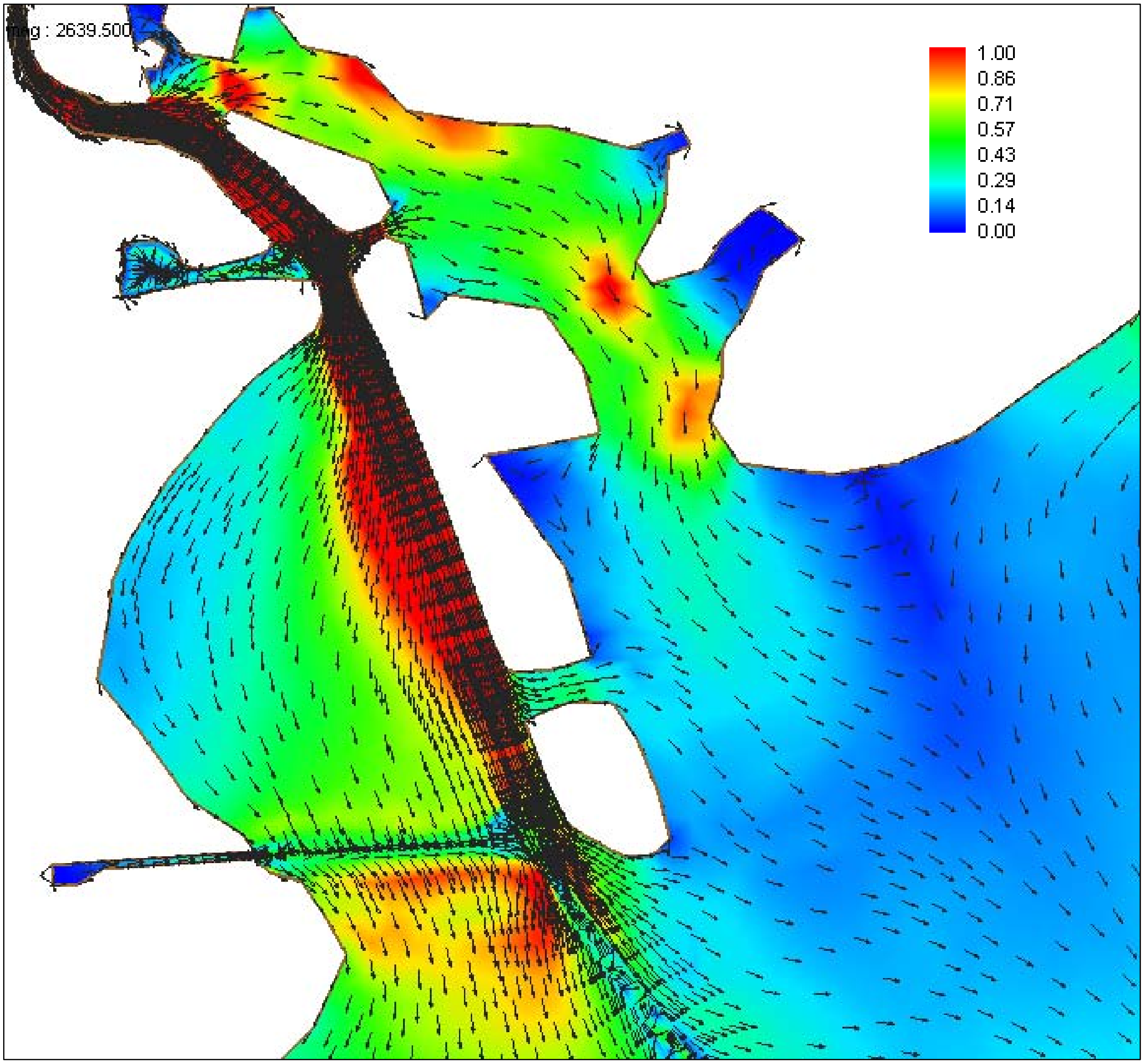

Figure 9. Velocity magnitude and direction at hour 2639.5 during high flow event for Base condition (ft/s).

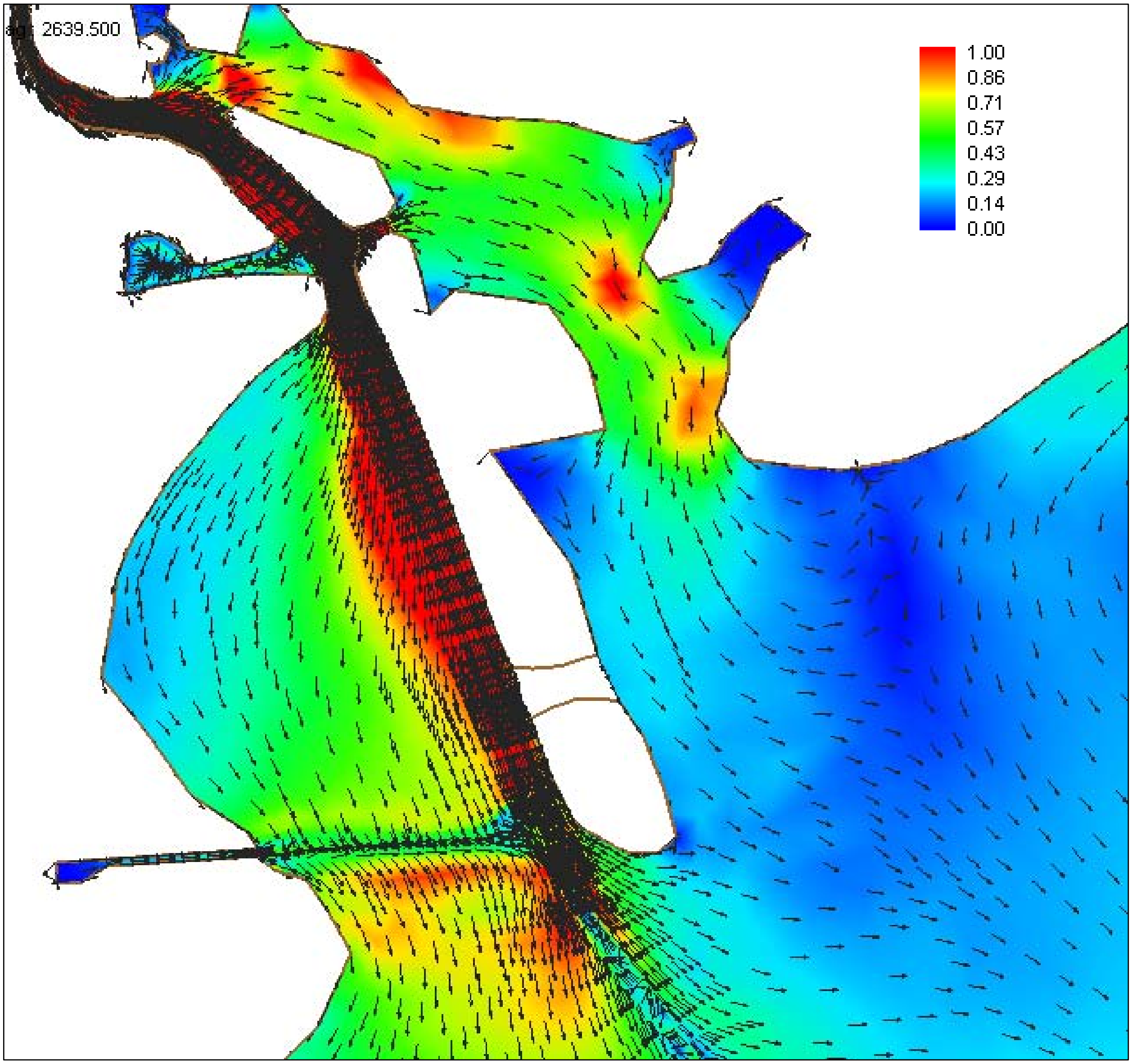

Figure 10. Velocity magnitude and direction at hour 2639.5 during high flow event for Plan 1 condition (ft/s).

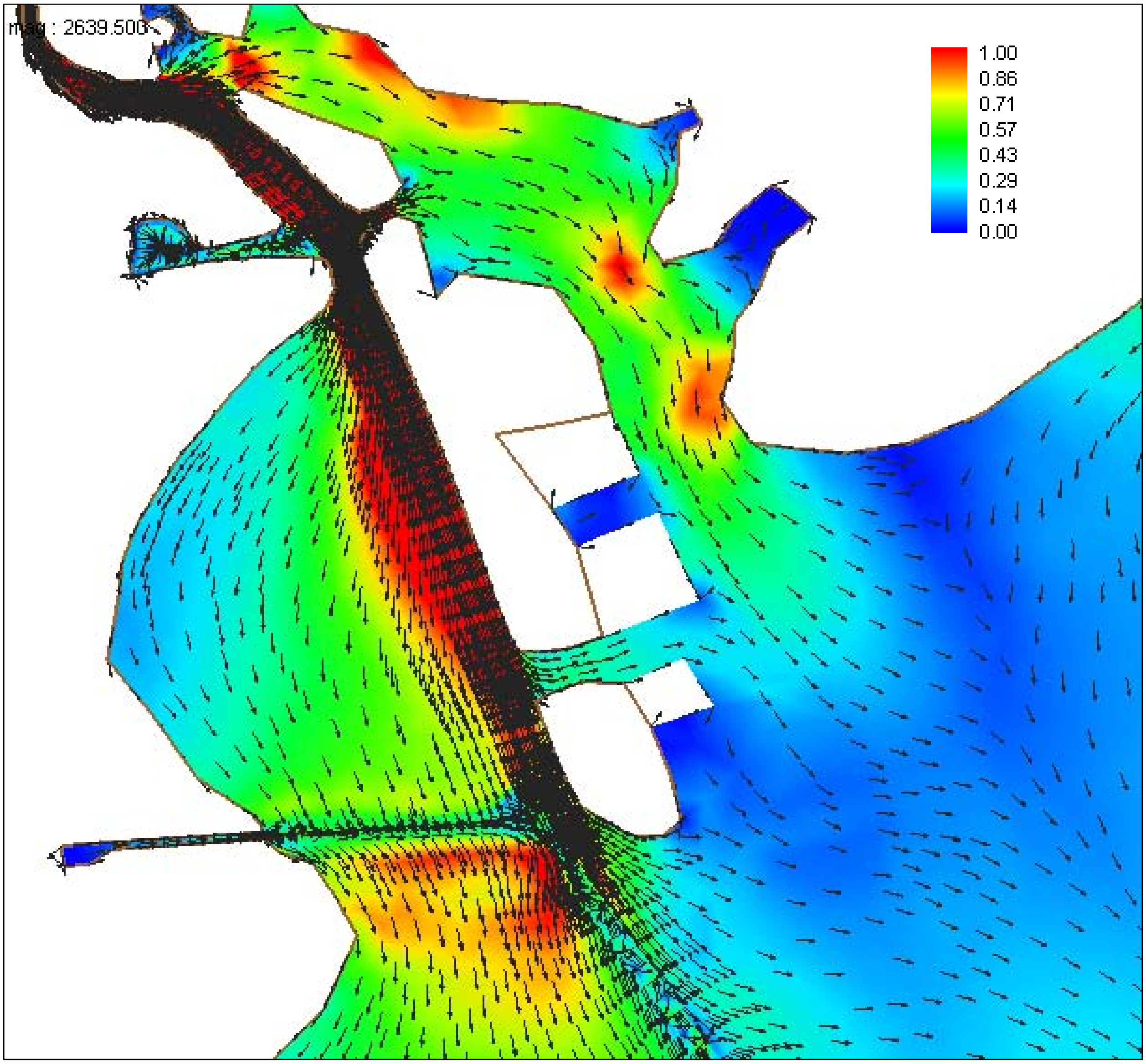

Figure 11. Velocity magnitude and direction at hour 2639.5 during high flow event for Plan 2 condition (ft/s).

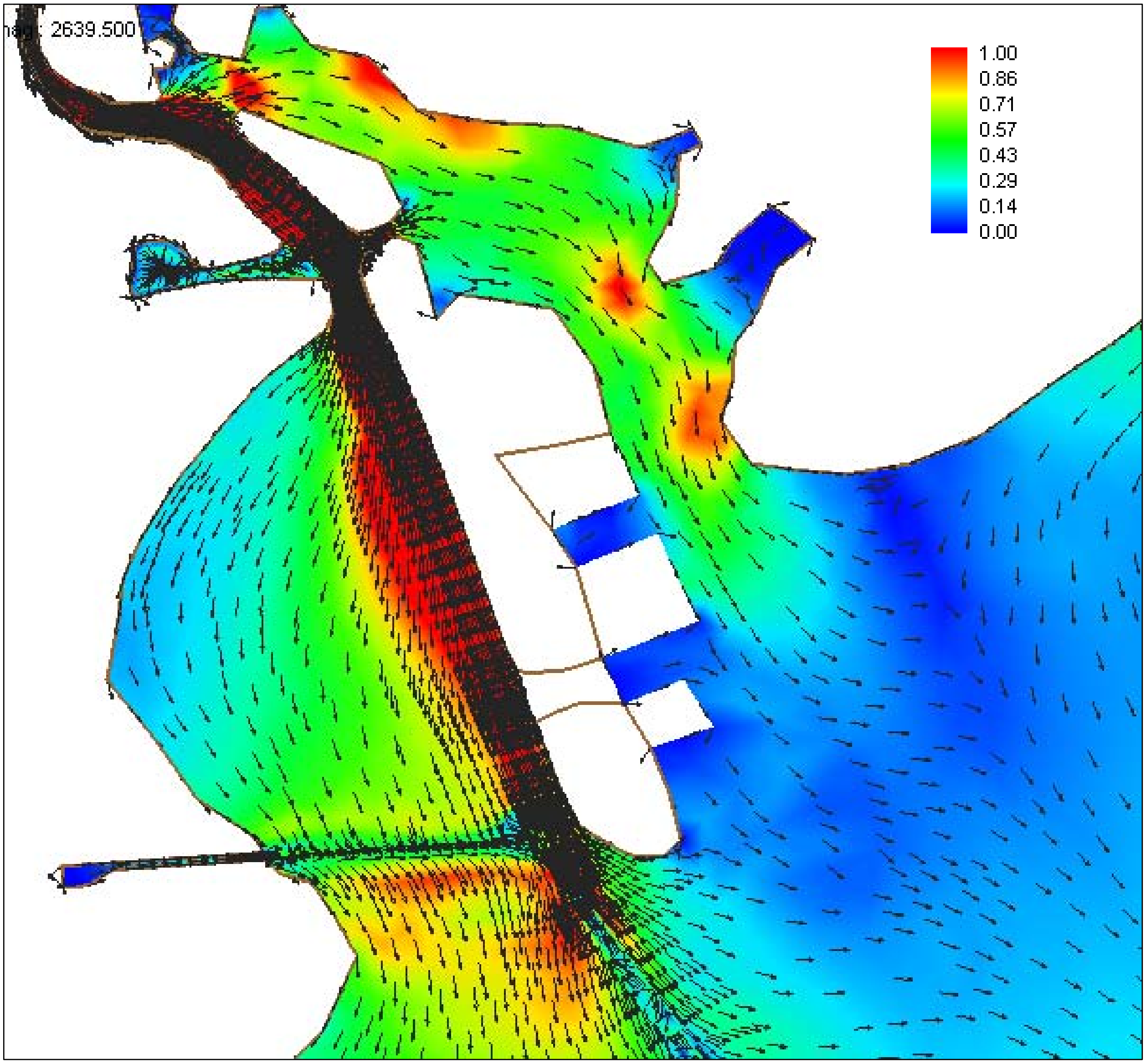

Figure 12. Velocity magnitude and direction at hour 2639.5 during high flow event for Plan 3 condition (ft/s).

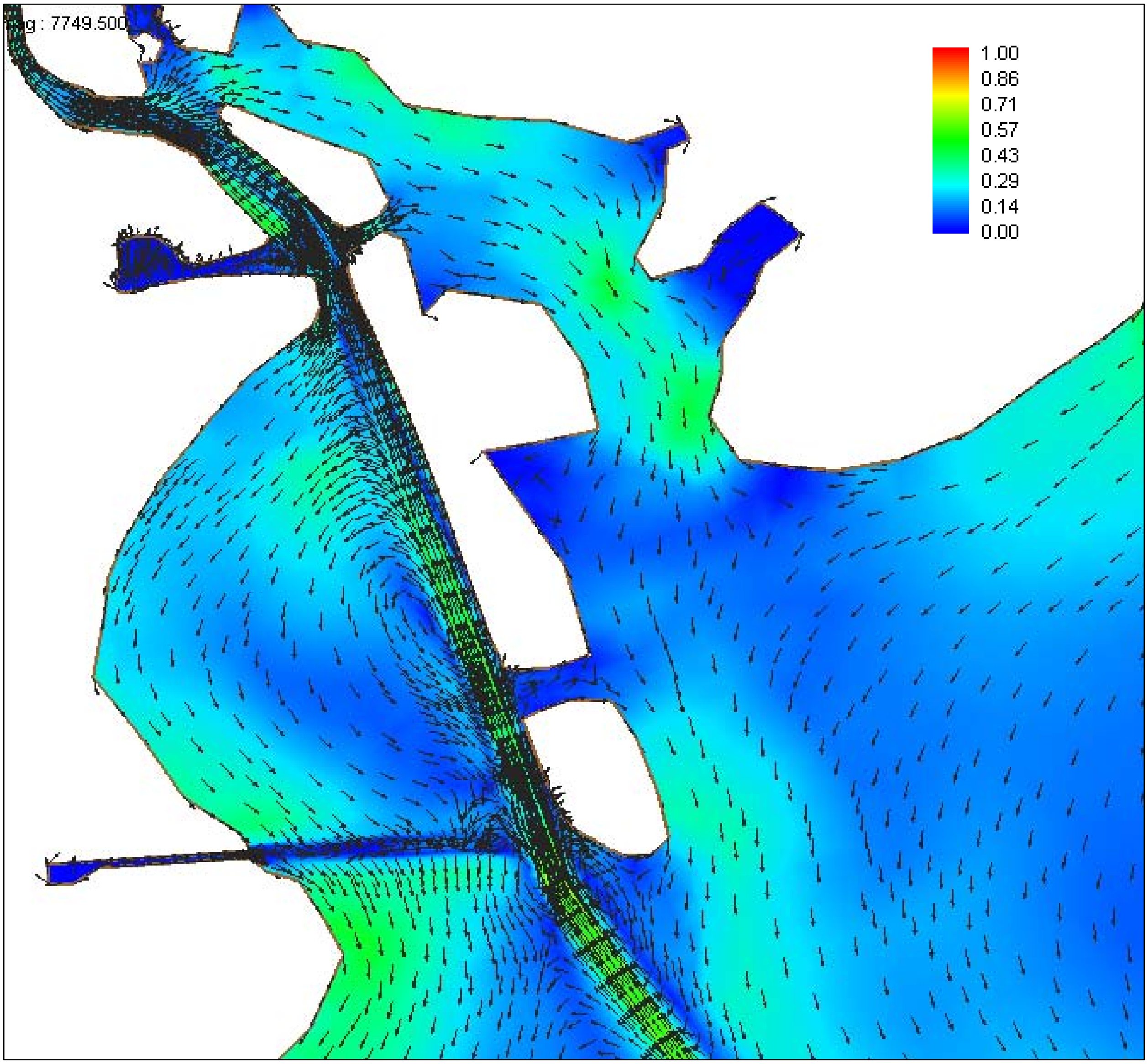

Figure 13. Velocity magnitude and direction at hour 7749.5 for Base condition (ft/s).

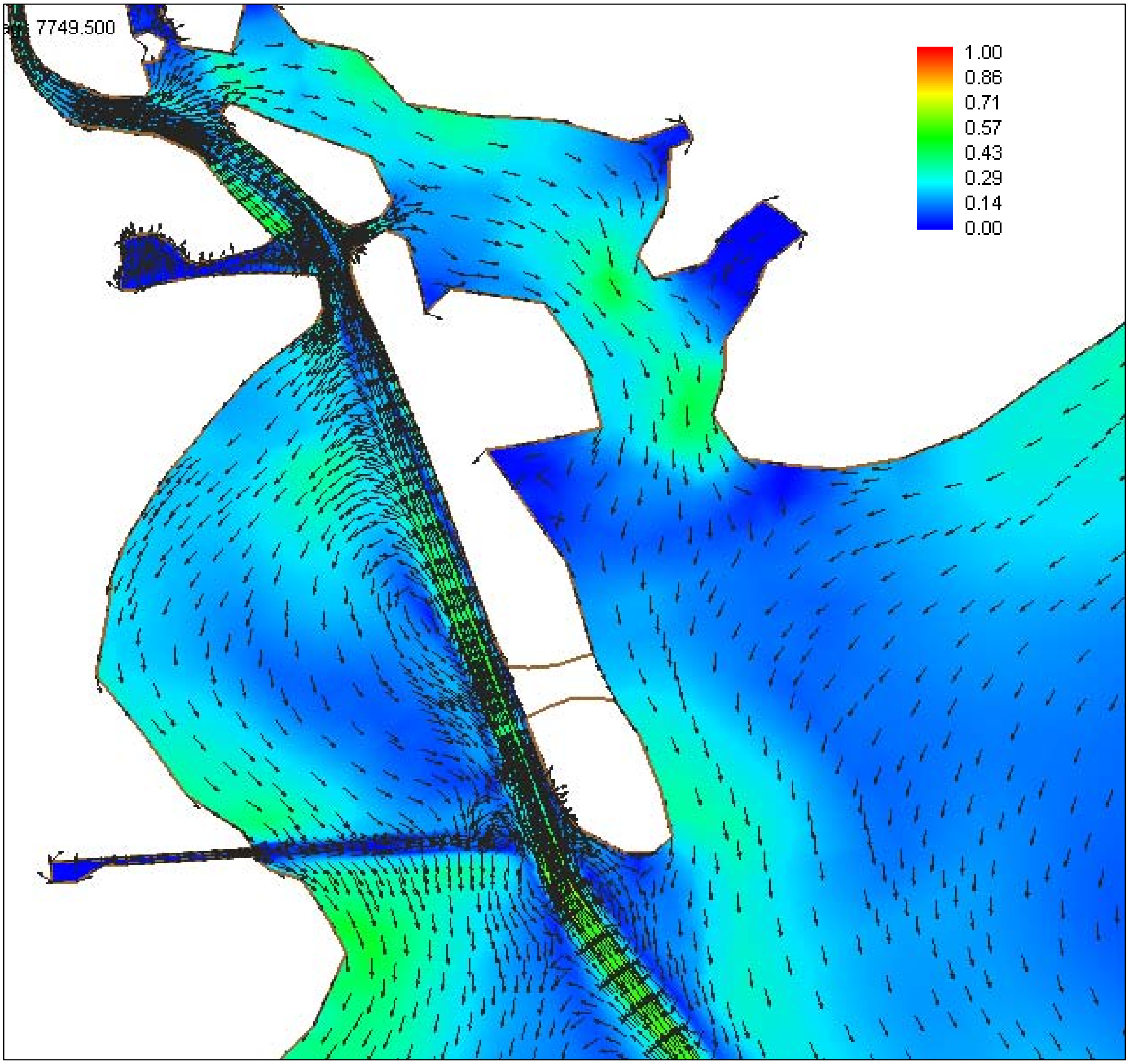

Figure 14. Velocity magnitude and direction at hour 7749.5 for Plan 1 condition (ft/s).

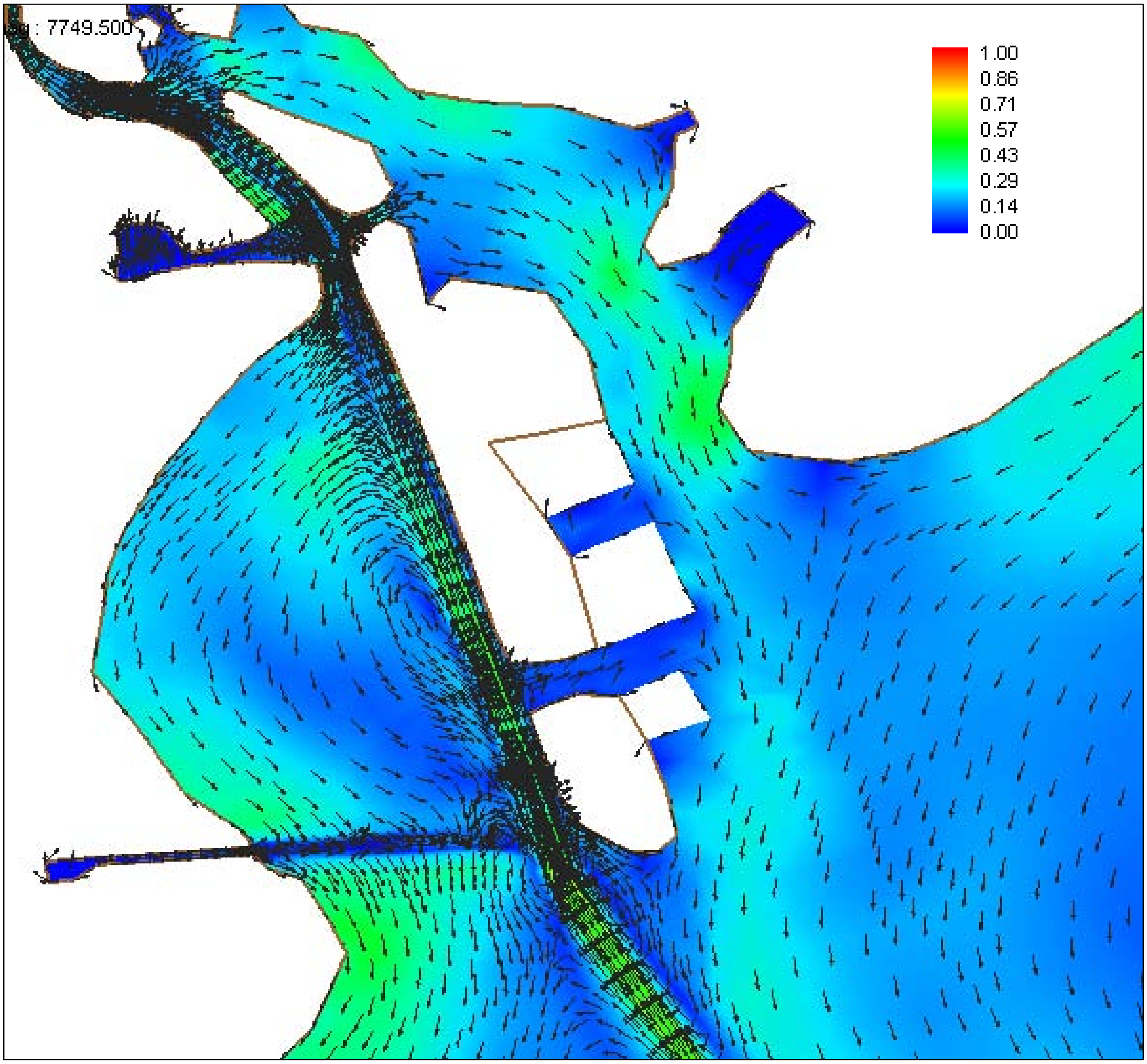

Figure 15. Velocity magnitude and direction at hour 7749.5 for Plan 2 condition (ft/s).

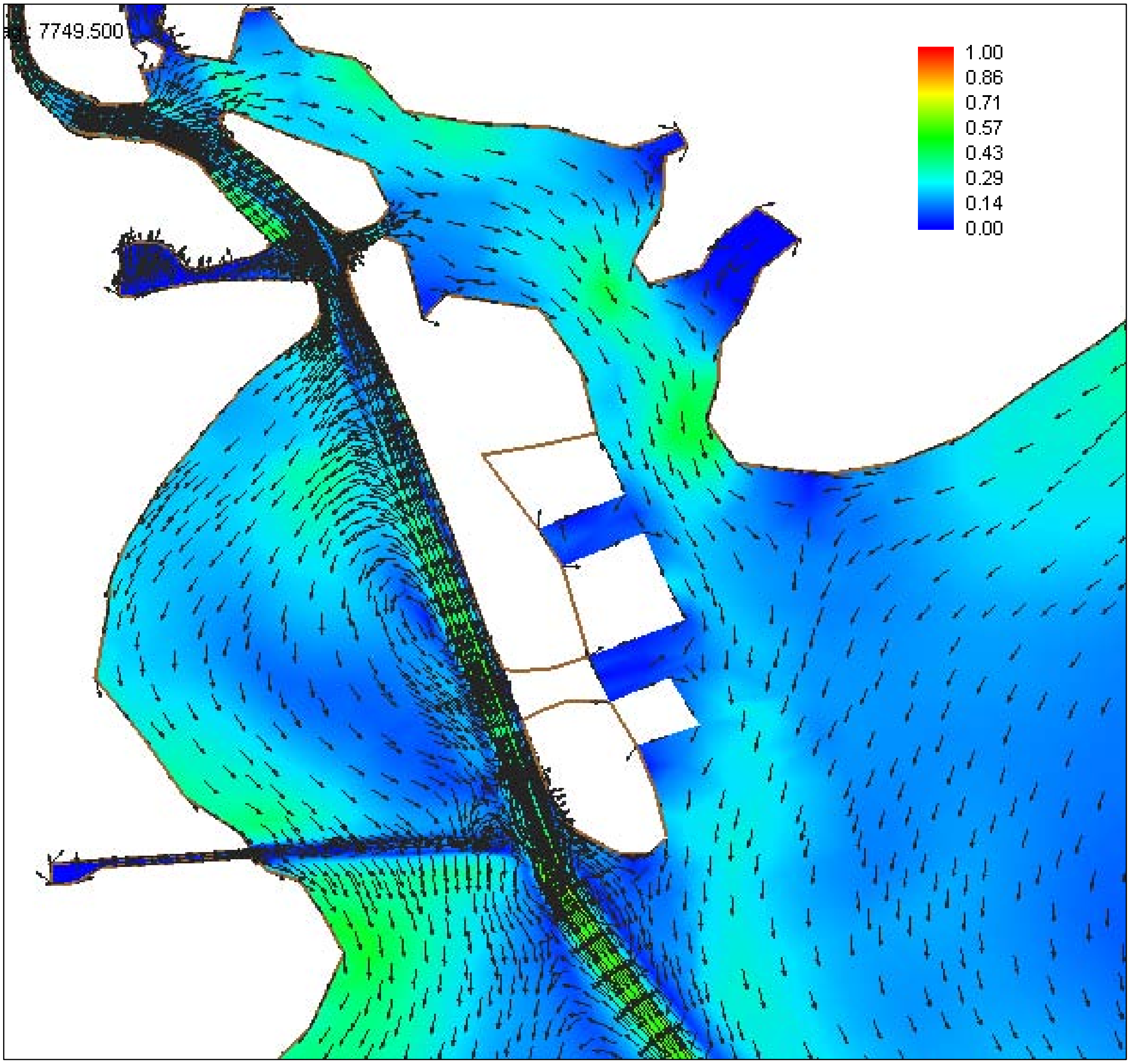

Figure 16. Velocity magnitude and direction at hour 7749.5 for Plan 3 condition (ft/s).

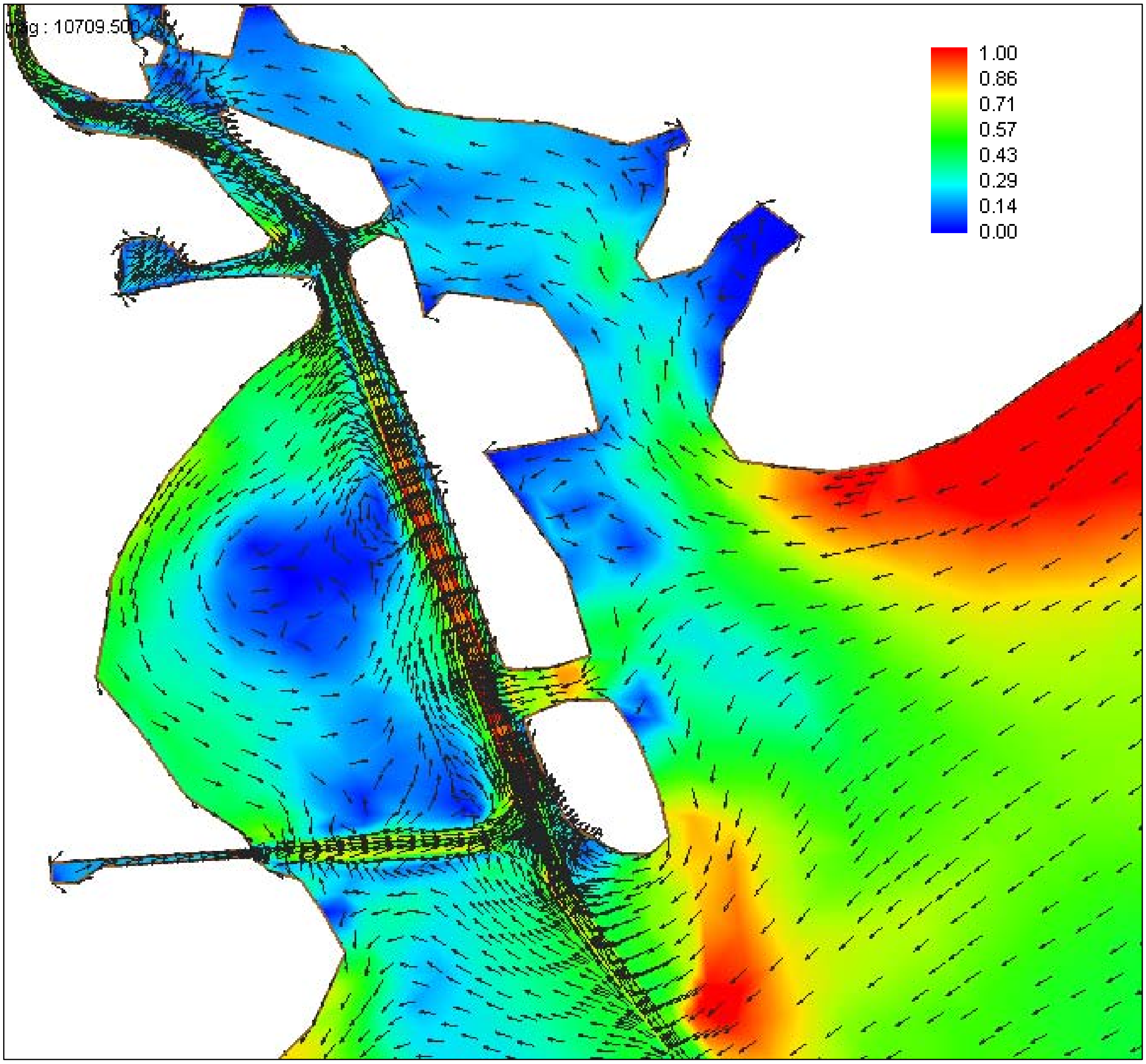

Figure 17. Velocity magnitude and direction at hour 10709.5 for Base condition (ft/s).

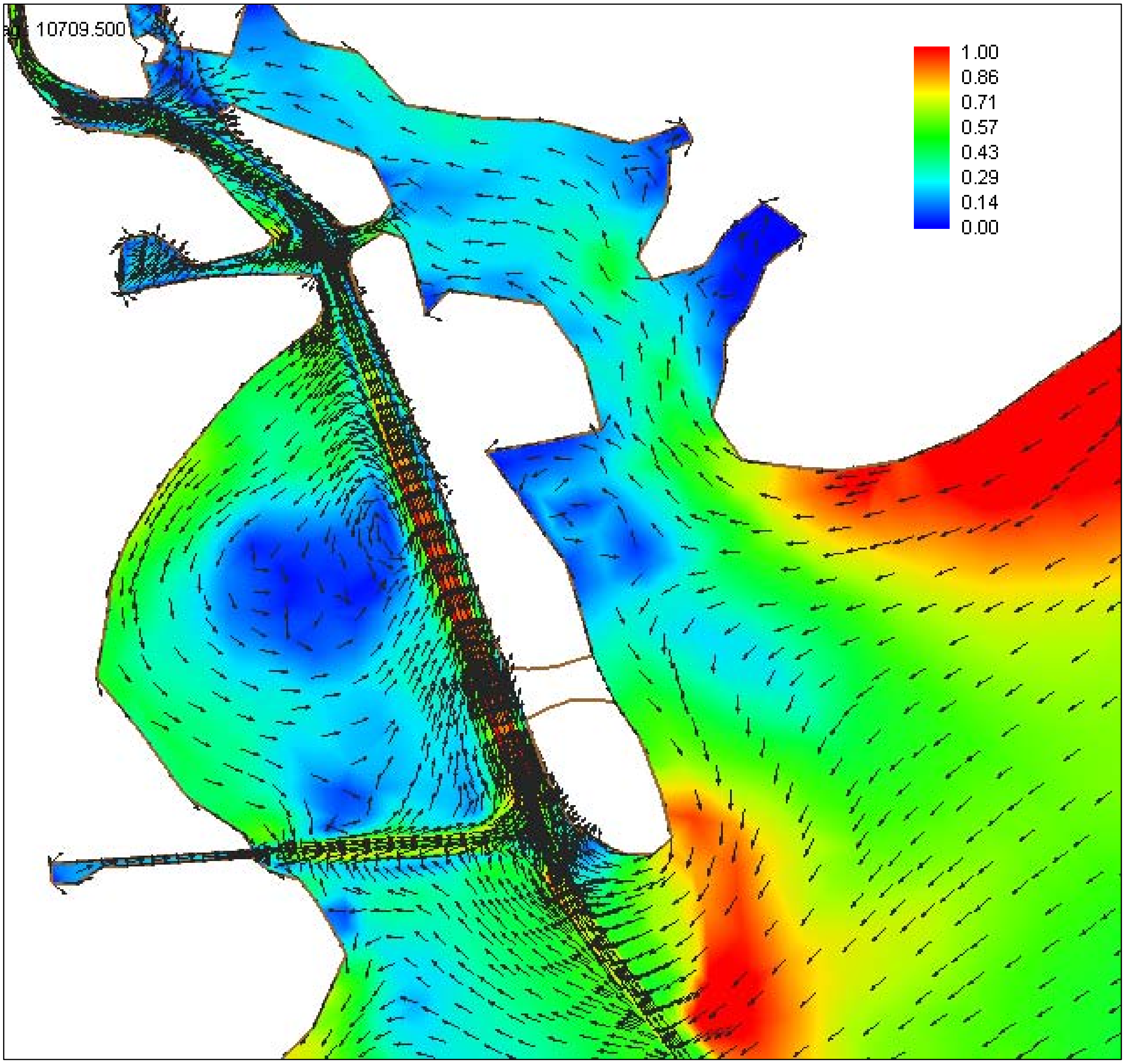

Figure 18. Velocity magnitude and direction at hour 10709.5 for Plan 1 condition (ft/s).

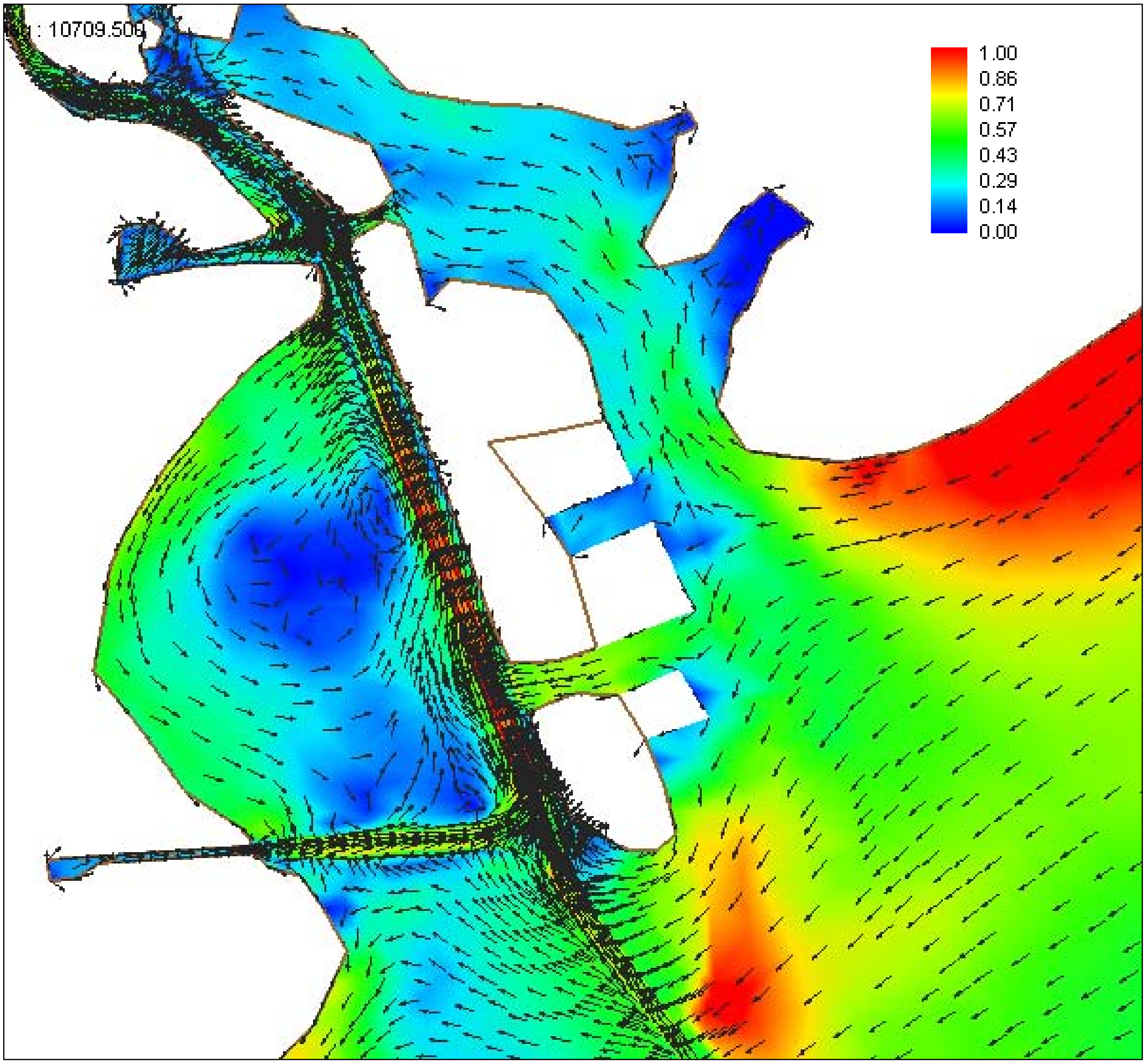

Figure 19. Velocity magnitude and direction at hour 10709.5 for Plan 2 condition (ft/s).

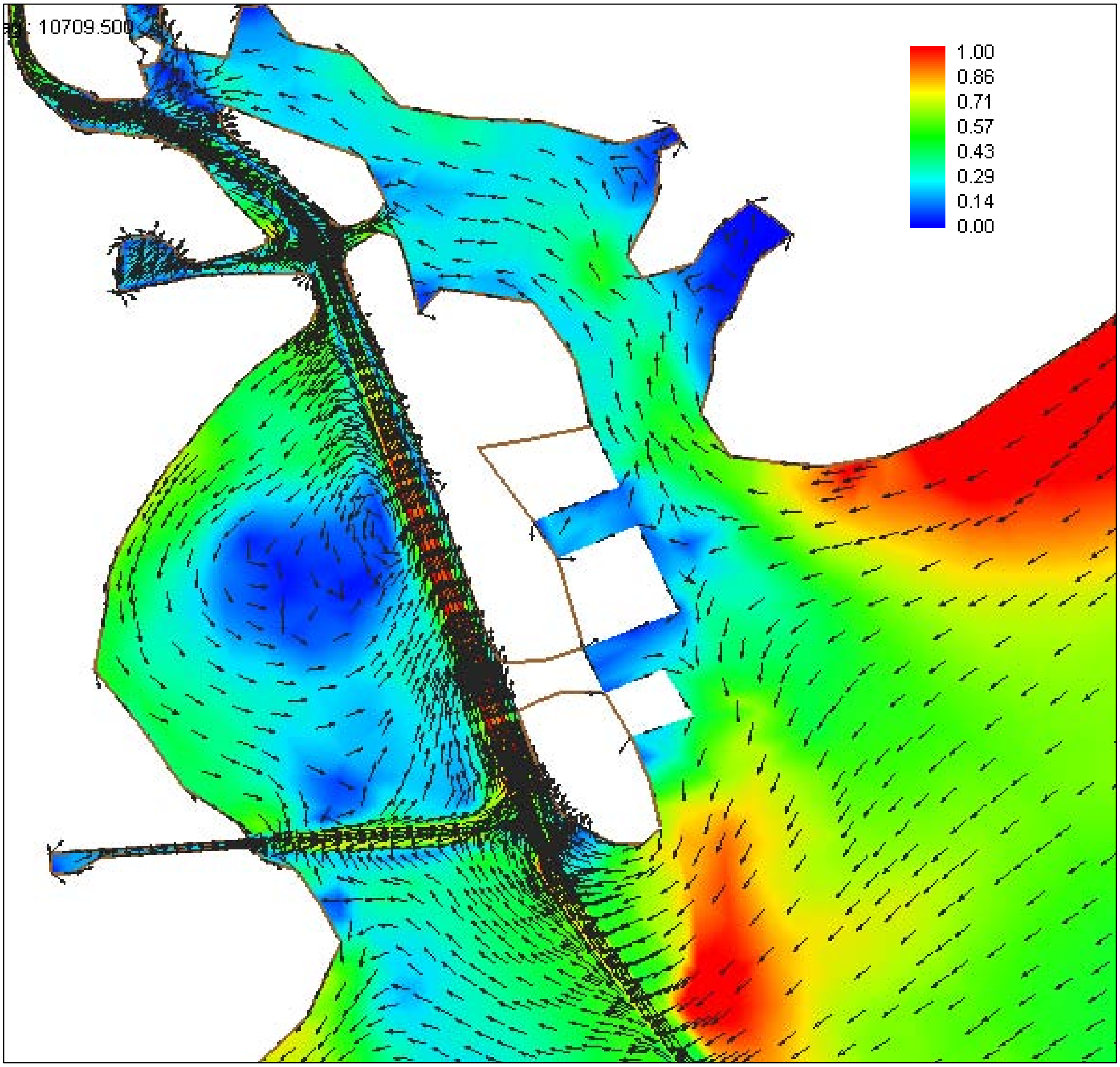

Figure 20. Velocity magnitude and direction at hour 10709.5 for Plan 3 condition (ft/s).

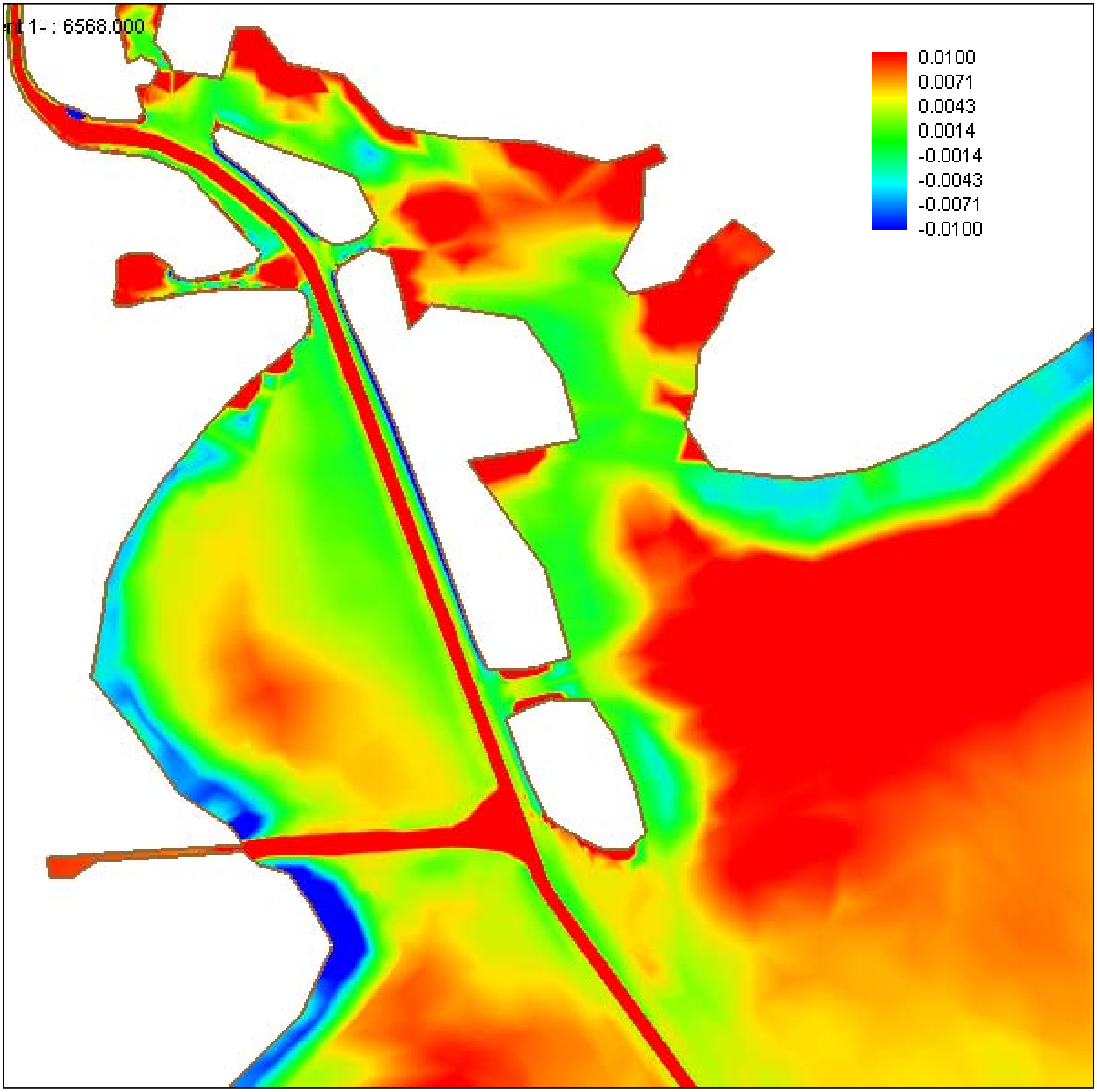

Figure 21. Bed displacement for Base at six months (m).

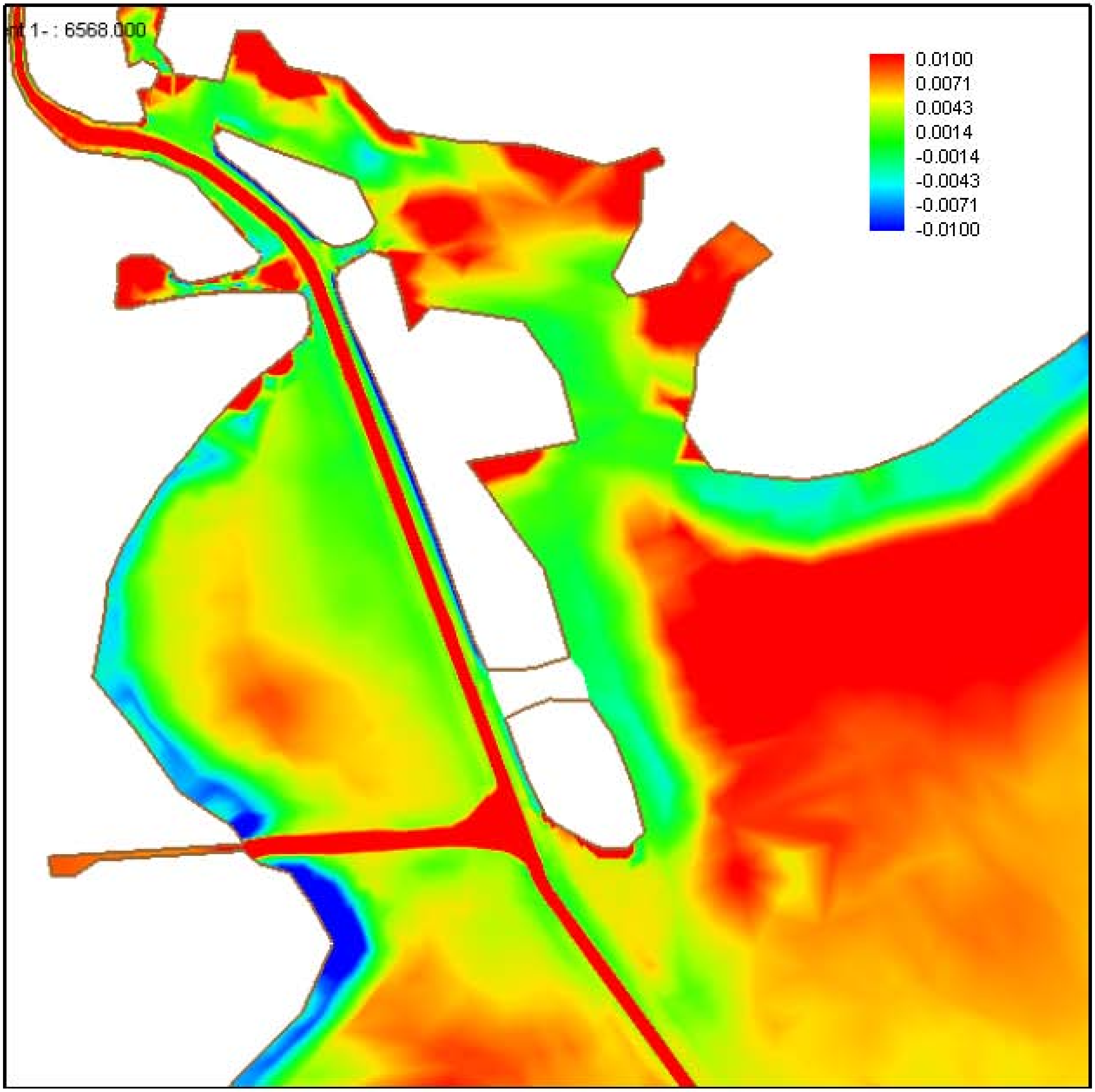

Figure 22. Bed displacement for Plan 1 at six months (m).

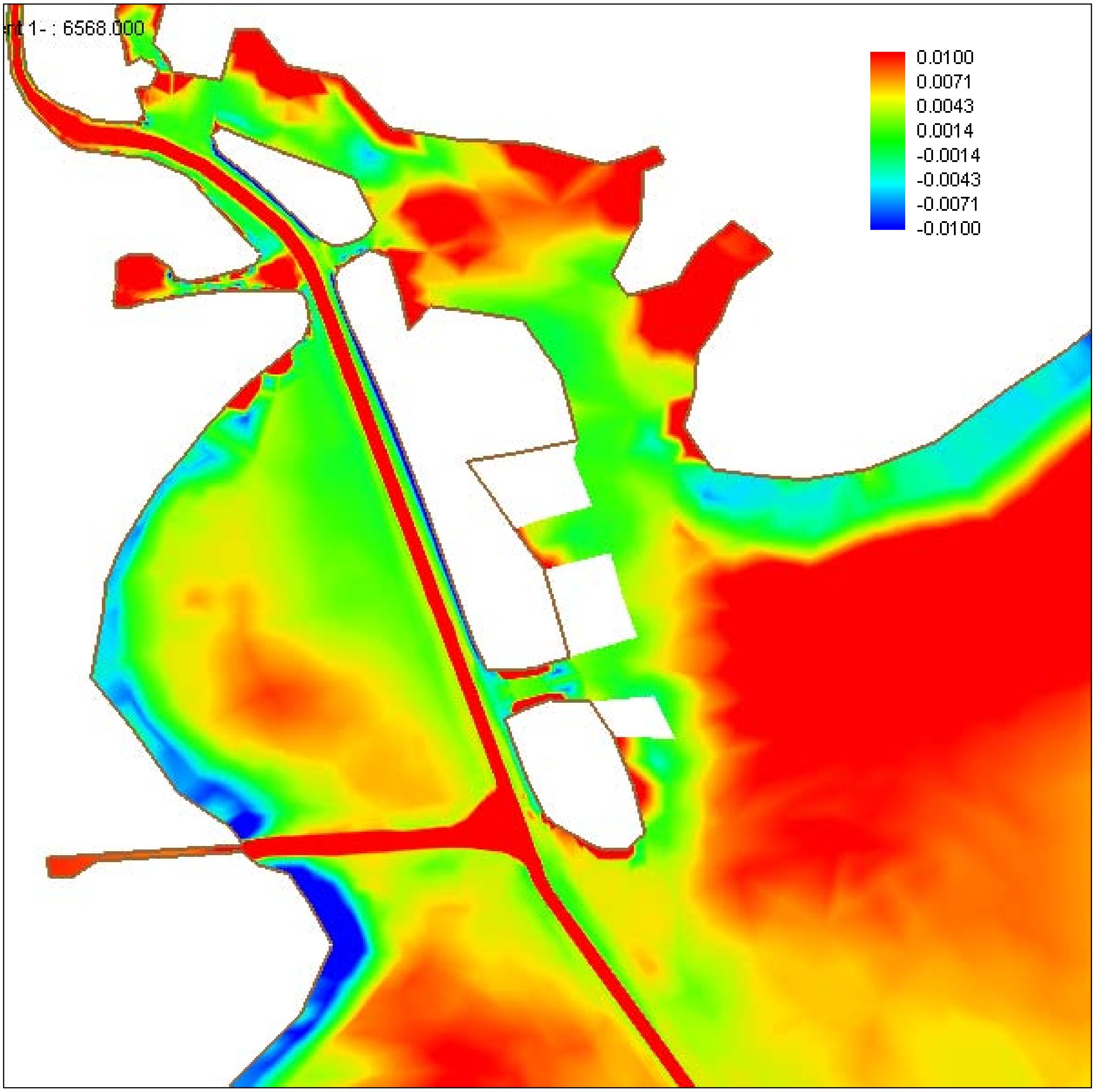

Figure 23. Displacement for Plan 2 at six months (m).

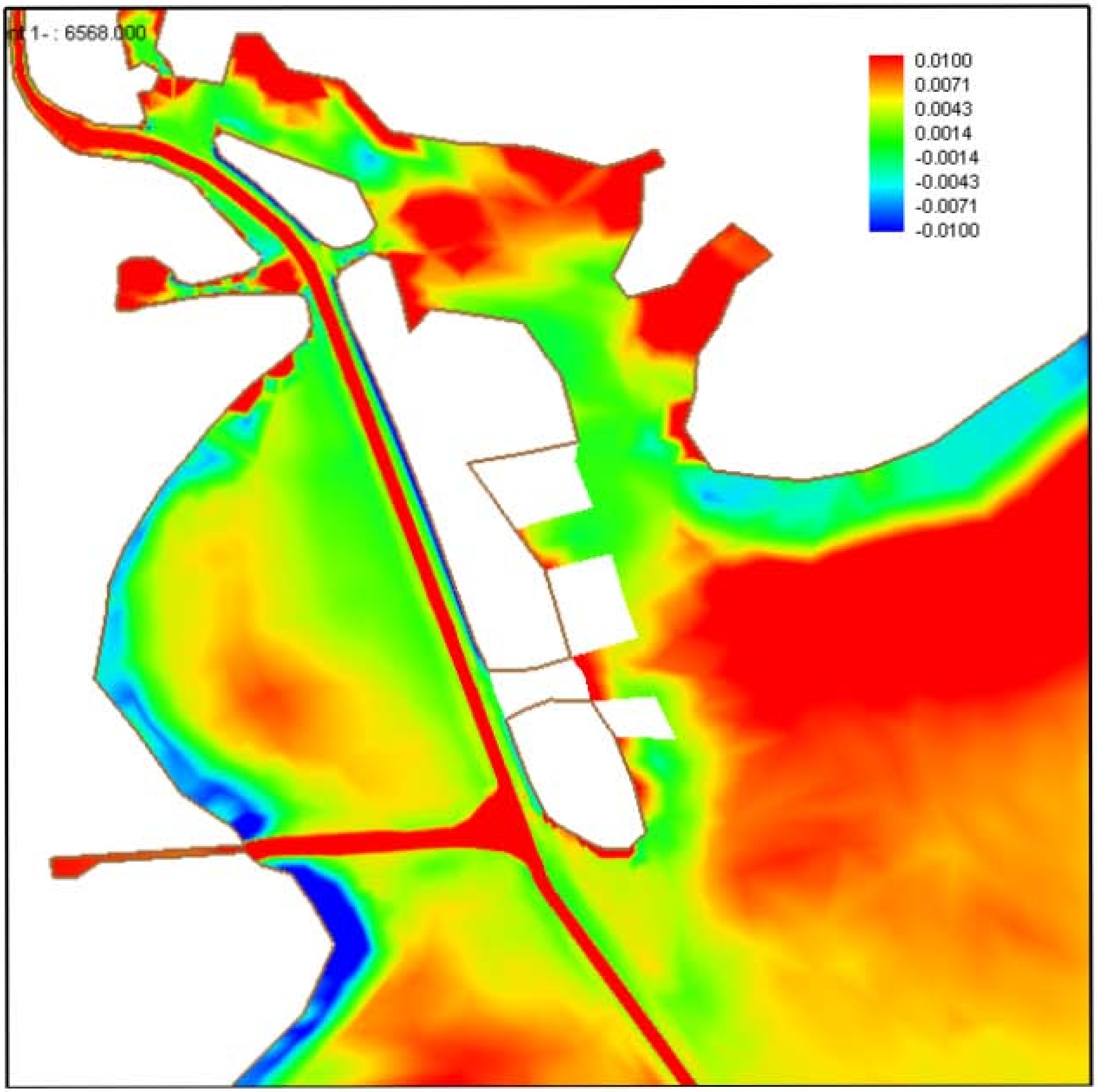

Figure 24. Bed displacement for Plan 3 at six months (m).

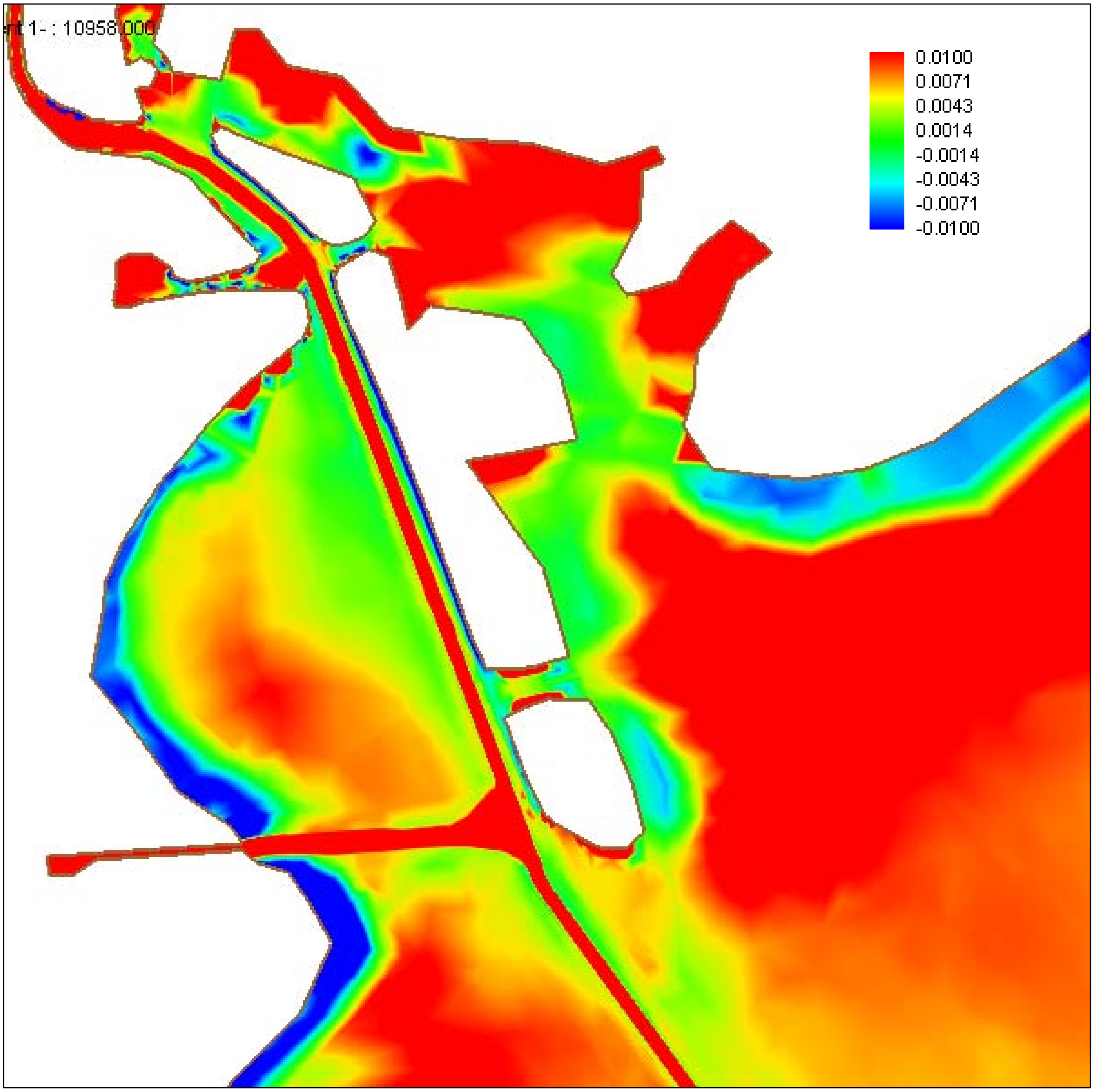

Figure 25. Bed displacement for Base at twelve months (m).

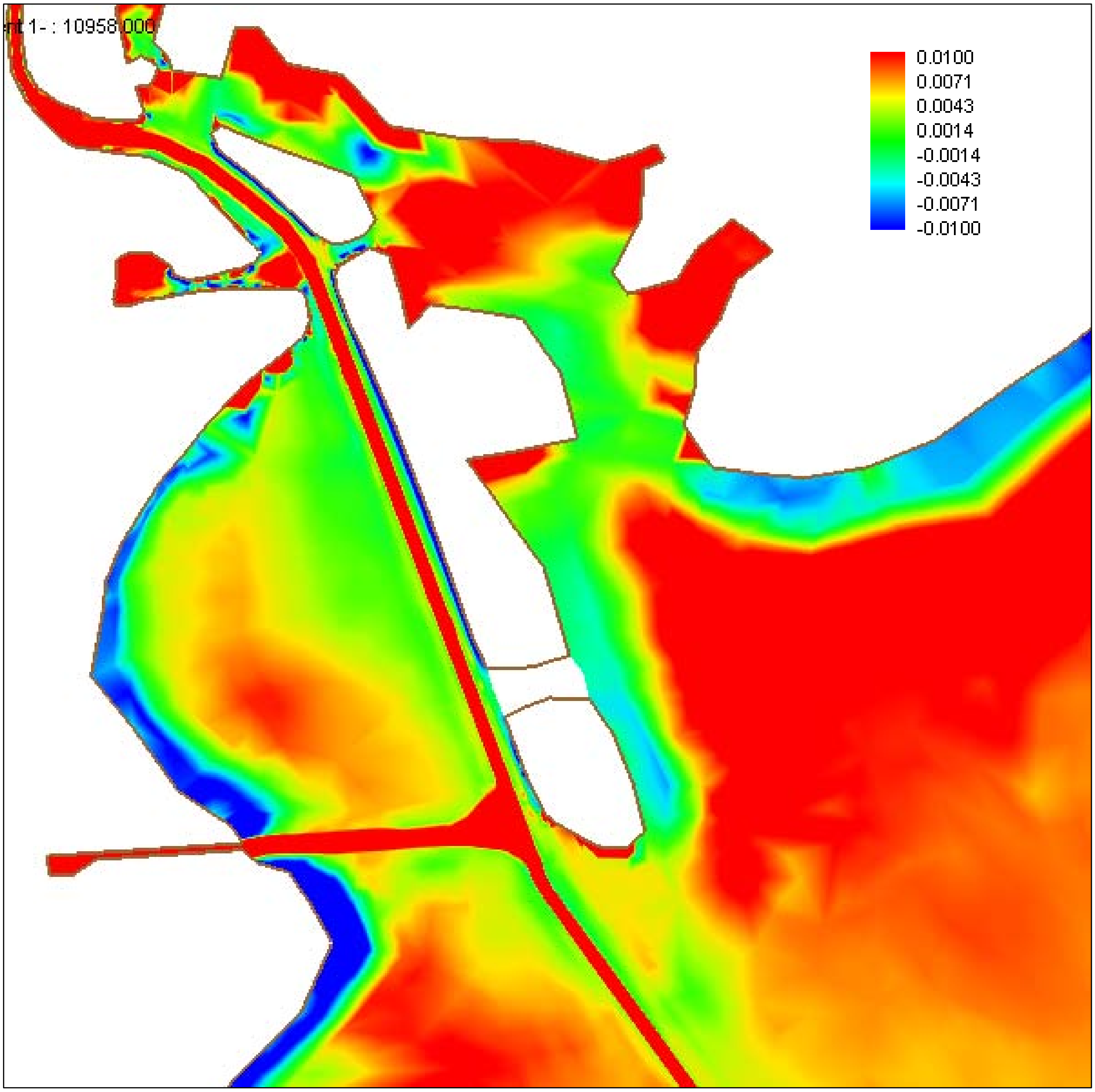

Figure 26. Bed displacement for Plan 1 at twelve months (m).

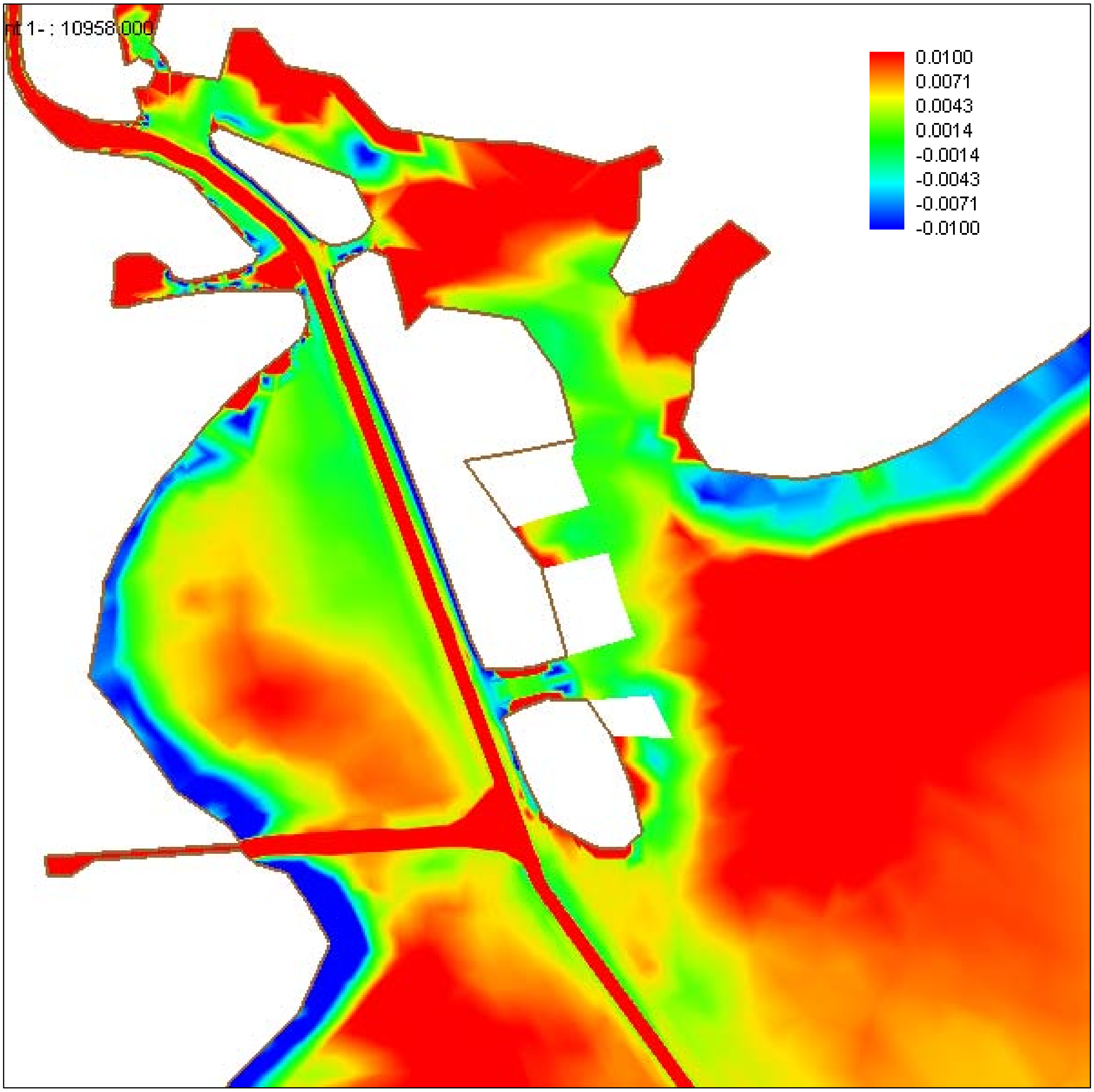

Figure 27. Bed displacement for Plan 2 at twelve months (m).

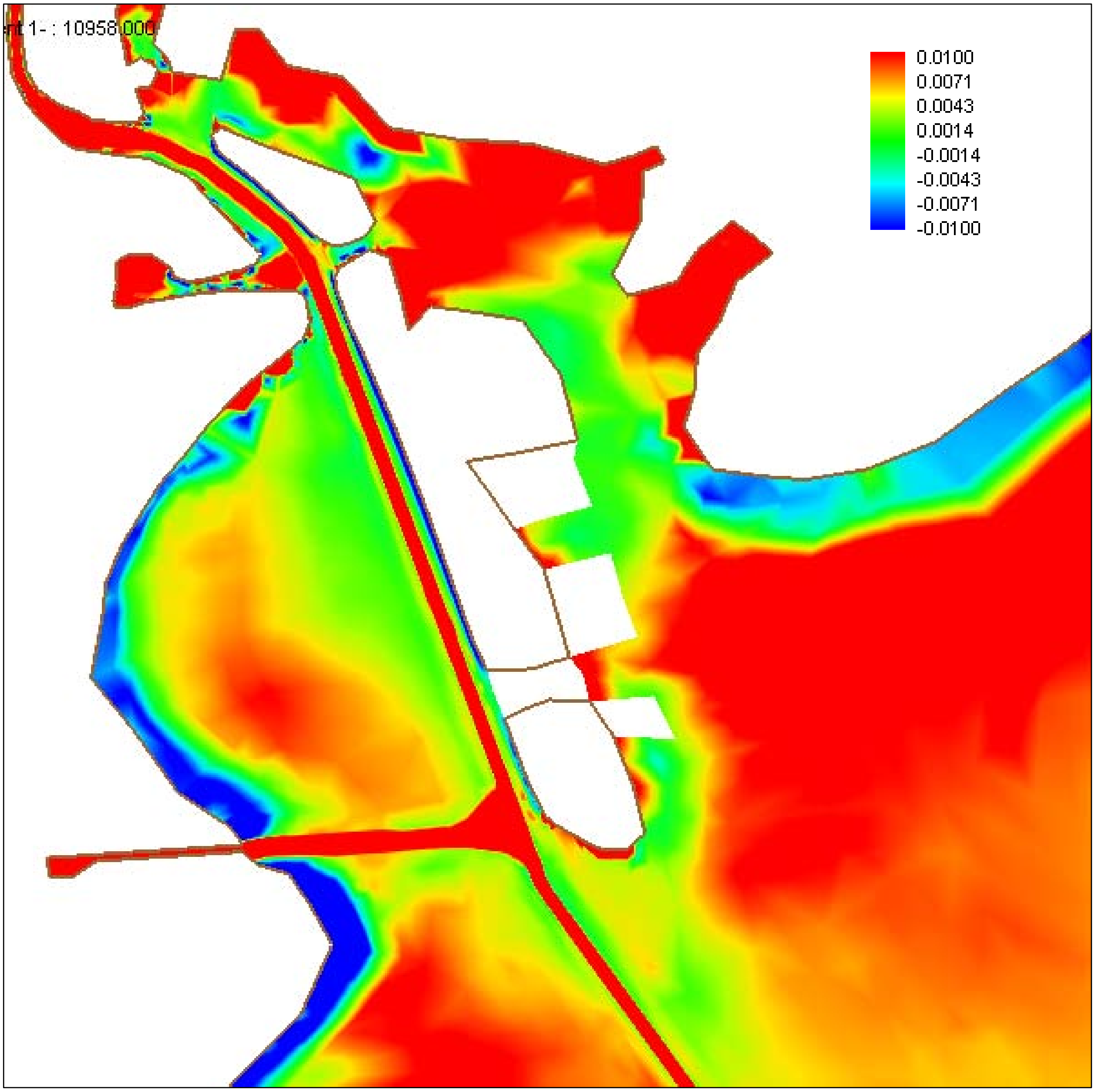

Figure 28. Bed displacement for Plan 3 at twelve months (m).

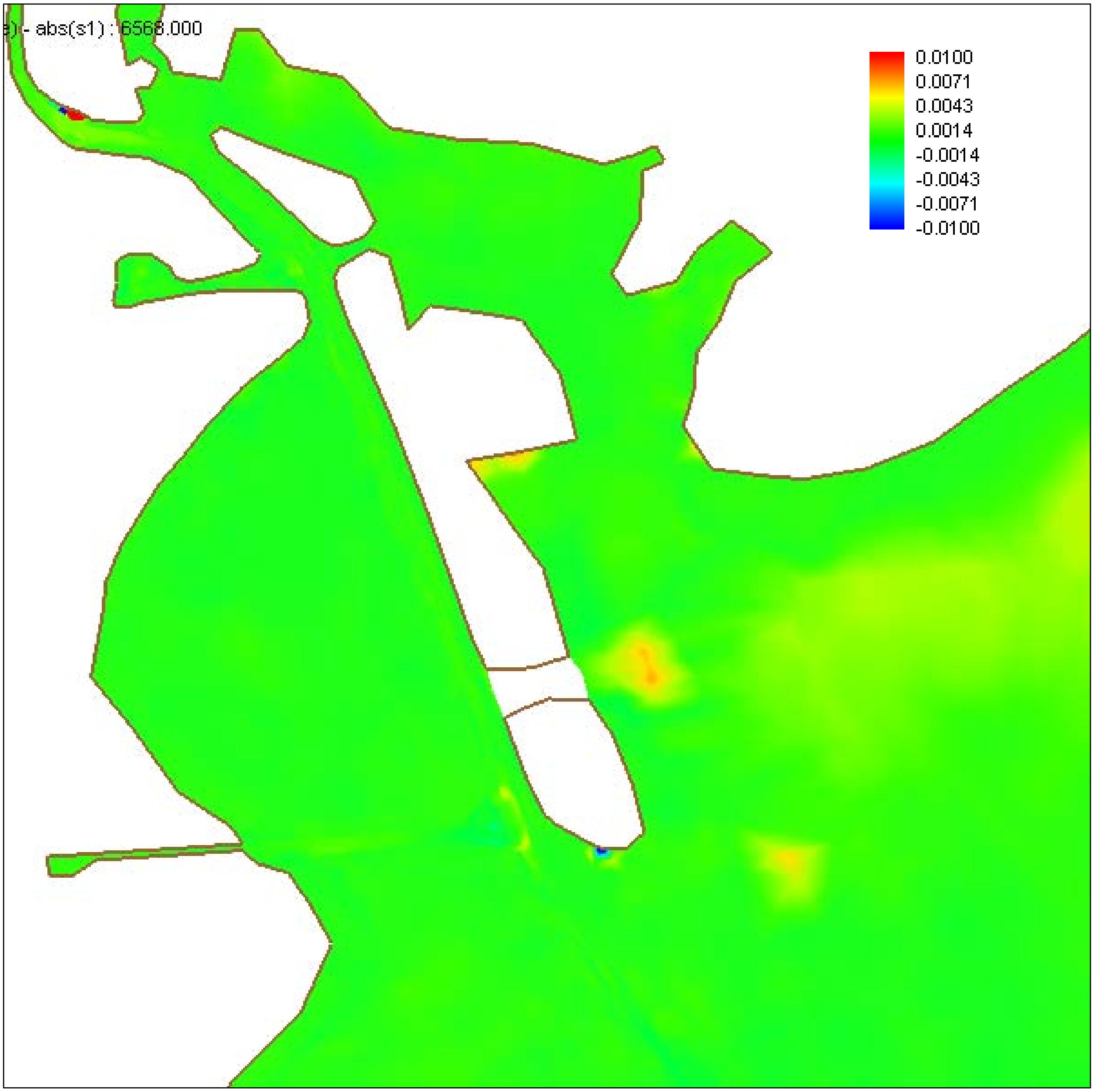

Figure 29. Difference in bed displacement magnitude of Plan 1 condition from Base at six months (Base – Plan 1).

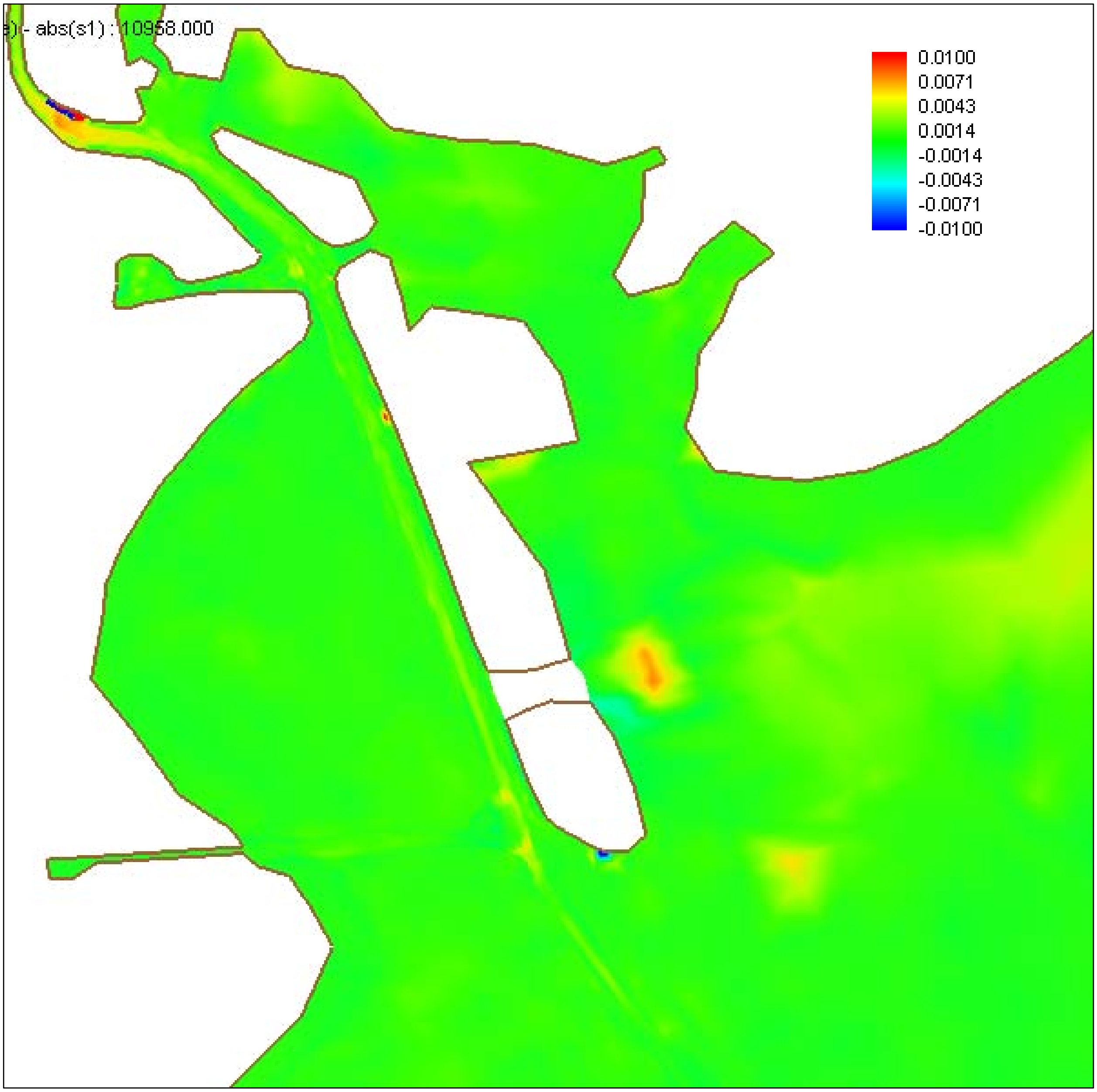

Figure 30. Difference in bed displacement of Plan 1 condition from Base at twelve months (Base – Plan 1).

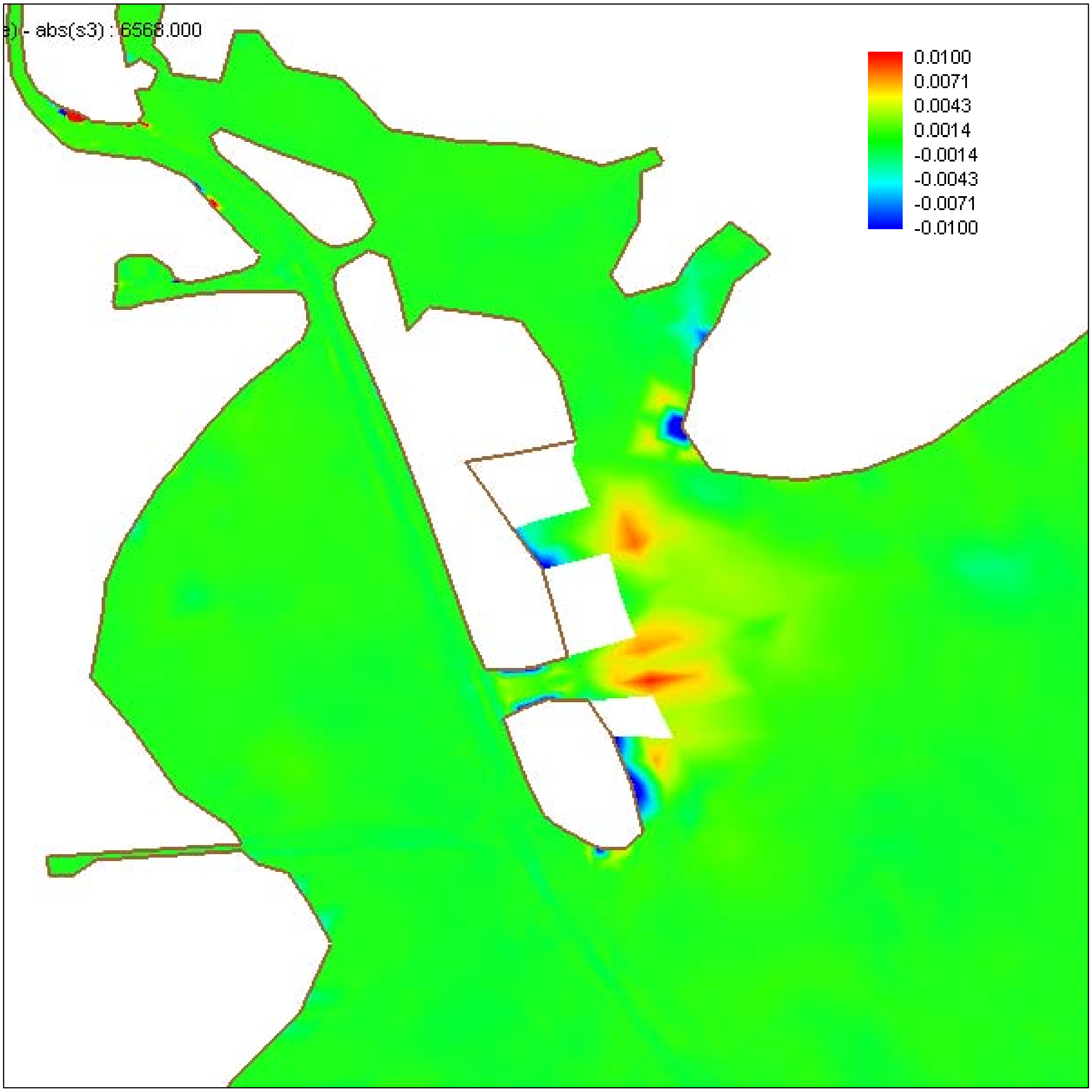

Figure 31. Difference in bed displacement magnitude of Plan 2 condition from Base at six months (Base – Plan 2).

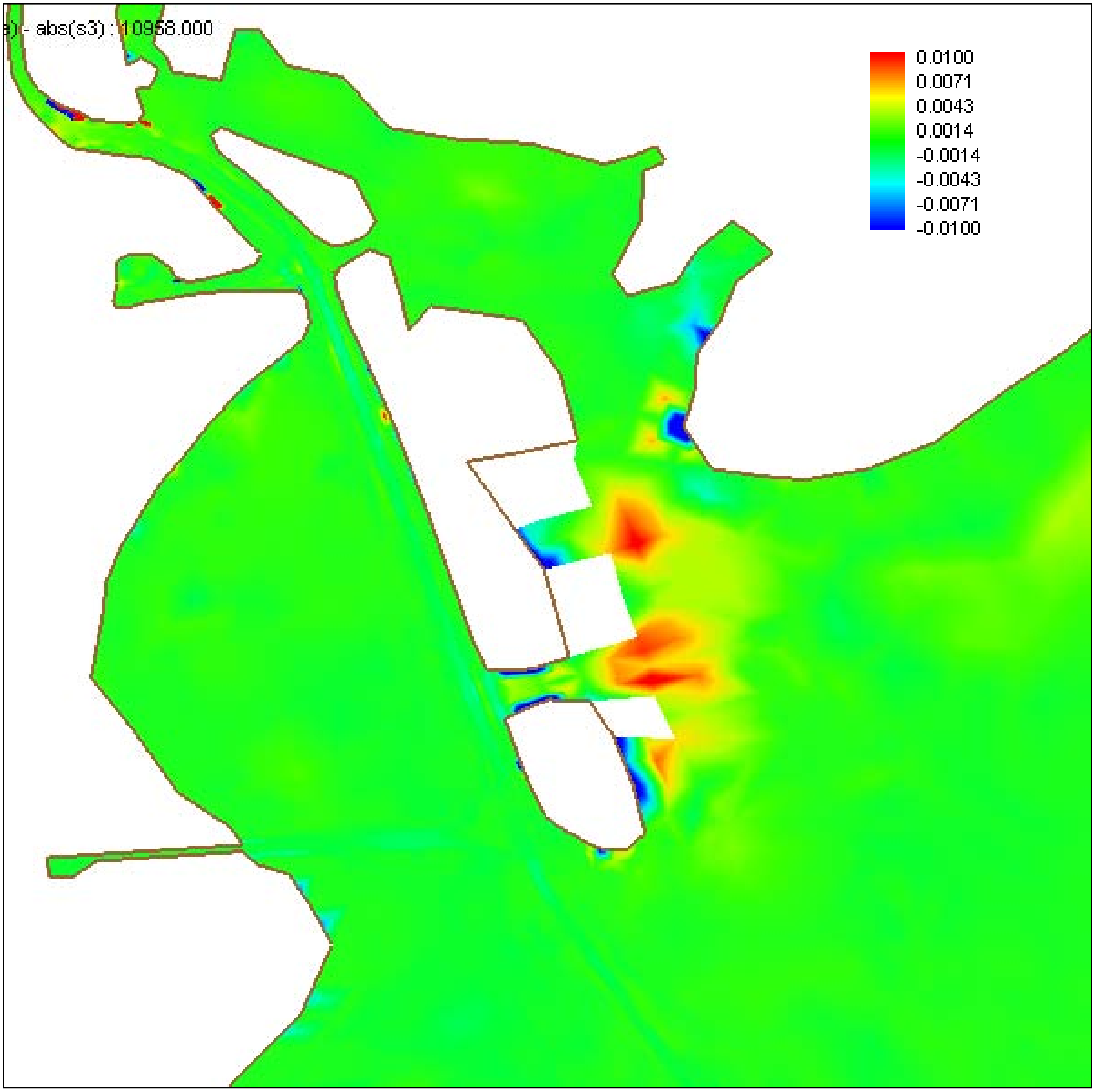

Figure 32. Difference in bed displacement of Plan 2 condition from Base at twelve months (Base – Plan 2).

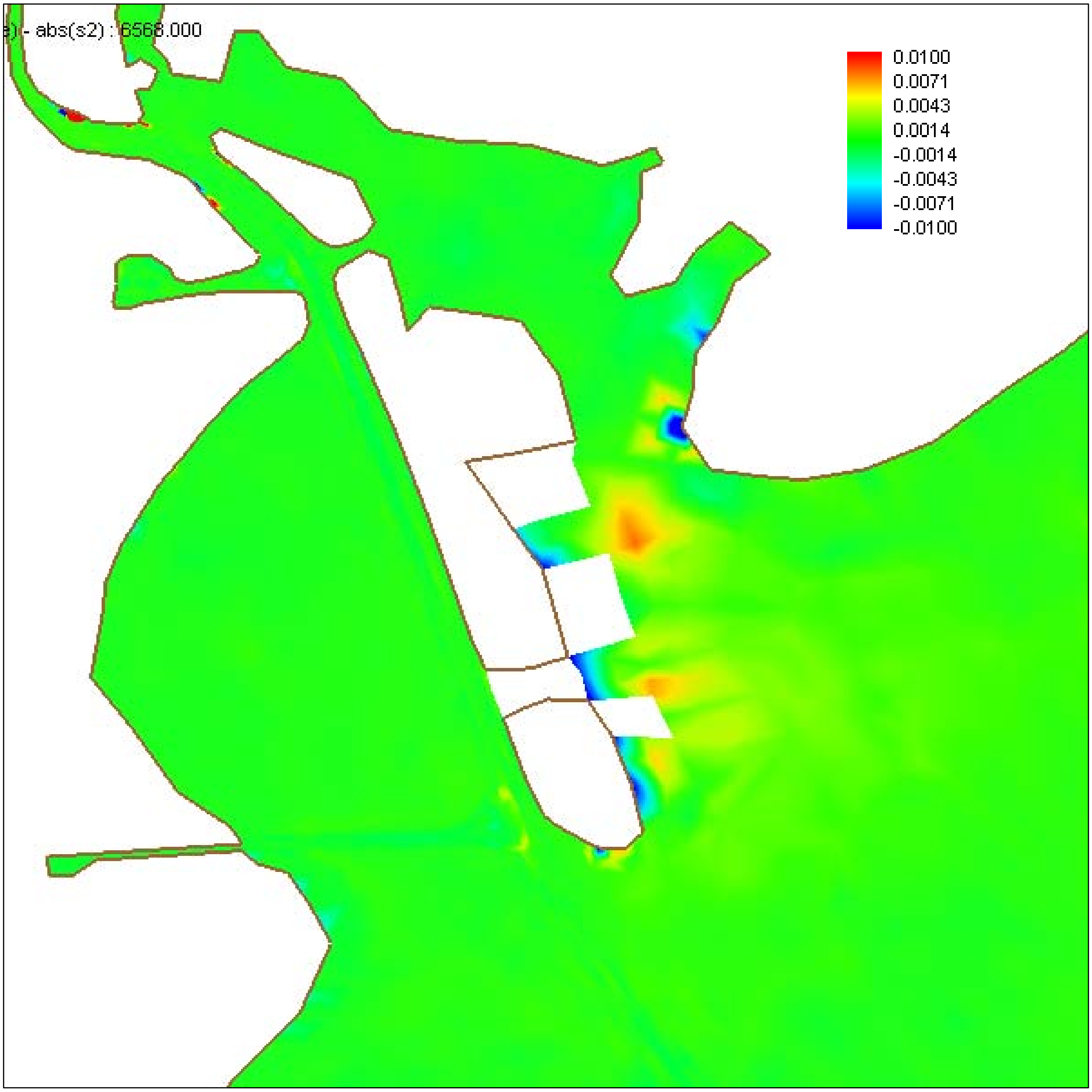

Figure 33. Difference in bed displacement magnitude of Plan 3 condition from Base at six months (Base – Plan 3).

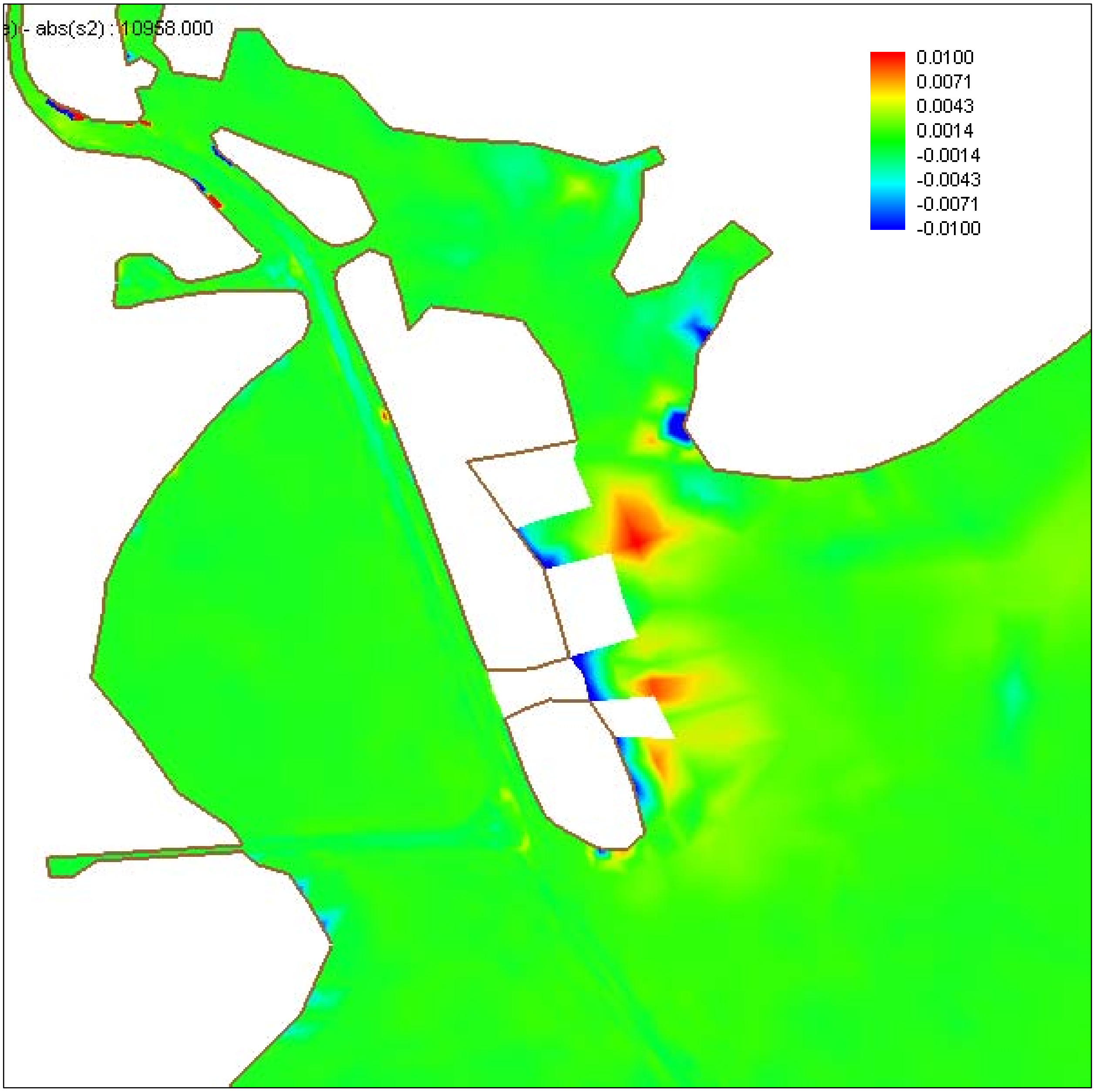

Figure 34. Difference in bed displacement of Plan 3 condition from Base at twelve months (Base – Plan 3).

These plan conditions do create changes in the channel shoaling, especially in the area along Atkinson Island and even southward down the channel. Figure 35 shows the displacement along the channel at the completion of the year-long simulation for the base and each plan condition from Morgan's Point to Bolivar Roads in meters. Figure 36 shows the percentage difference from base in the channel shoaling for each plan.

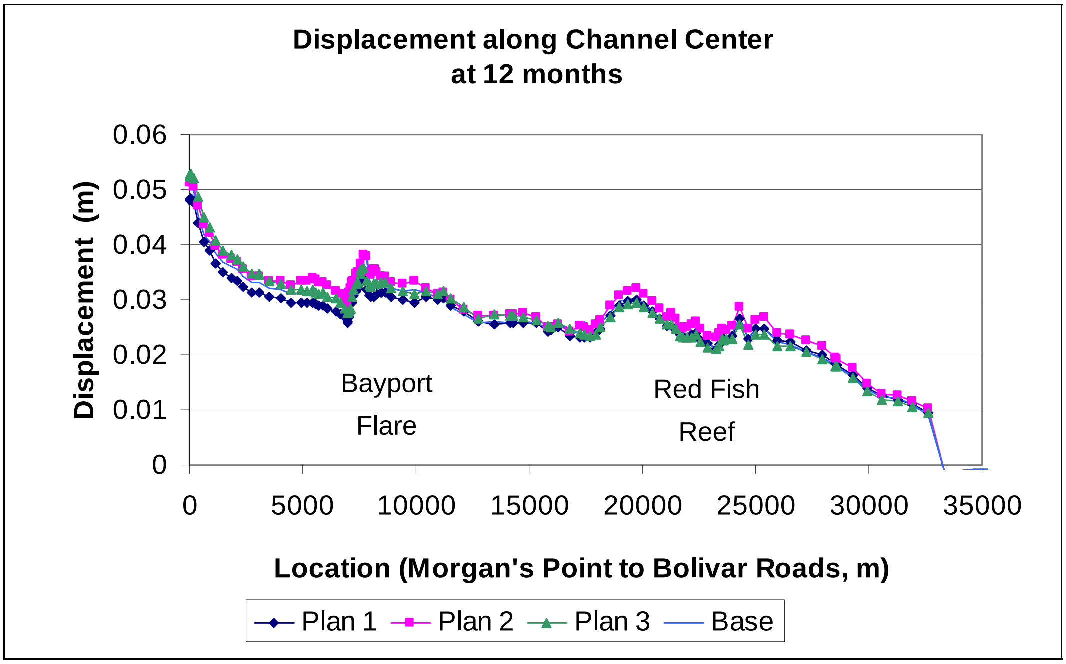

Figure 35. Channel bed displacement after 1-year for Base and all three plans.

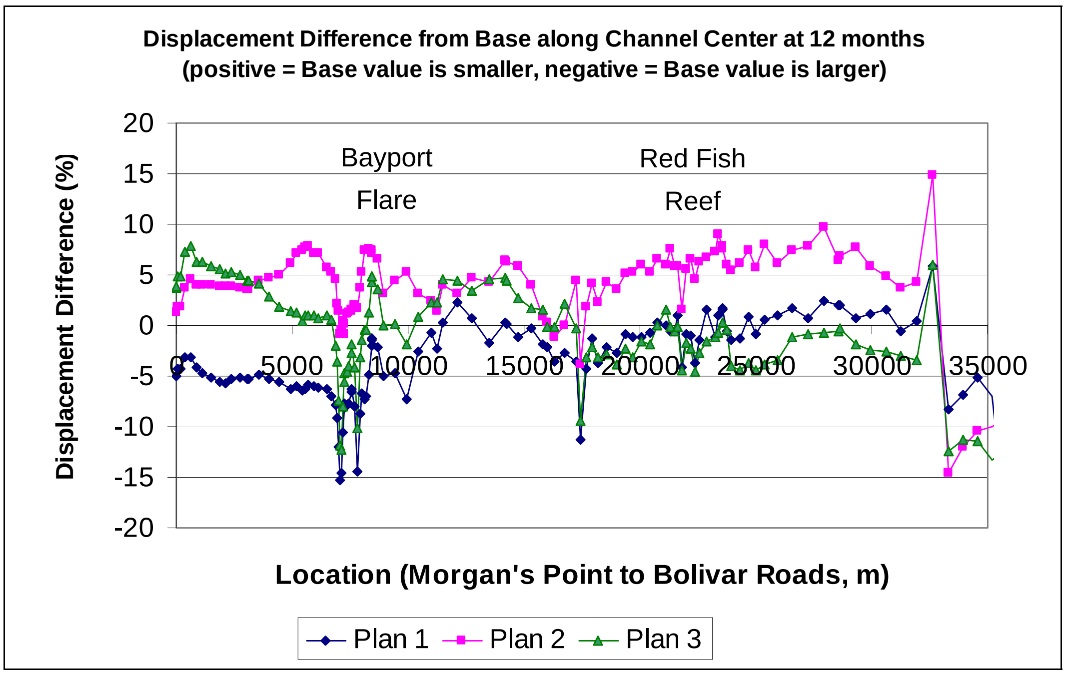

Figure 36. Percentage difference in channel bed displacement from Base for all three plans.

The various plan conditions generate changes in the sedimentation in the area along the east side of Atkinson Island as well as into the ship channel. Plan 1 allows for more erosion along the east side of the island due to the removal of the gap between PA 14 and PA 15. There is also slightly less deposition in the shallows just north and south of the Bayport flare, as well as a decrease in deposition in the channel north of the flare. The major differences due to Plan 2 modifications are in the location of the gap and on the eastern side of the island. There is more erosion and less deposition in respective areas of the gap, therefore generating an increase in shoaling in the channel north of the Bayport flare. Plan 2 did generate locations of less deposition around the perimeters of the added disposal sites, except just south of M8, due to the change in the flow patterns. Plan 3, which combined the modifications due to Plan 1 and Plan 2, experienced similar changes around the additional disposal sites as observed from Plan 2, but the closure of the gap did not increase the deposition in the channel as much as Plan 2, and the deposition was actually reduced from the base condition in the vicinity of the Bayport flare and southward. Generally, filling the gap between PA 14 and PA 15 reduces the shoaling in the channel in the Bayport Flare area and the addition of the marsh sites generates an equal or increased amount of shoaling in the ship channel along the northern section of Atkinson Island. For all plan alternatives the increase in shoaling along the channel at the conclusion of one year is less than 10 percent from the base condition. However, the decrease in channel shoaling after one year is as high as 15 percent in places. All three plans also show changes in the shoaling south of the Mid Bay Marsh site (see Figure 6). Plan 2 shows approximately a 5 percent increase in the shoaling in this lower section while Plans 1 and 3 show slight increases and decreases with magnitudes less than 5 percent. It is important to note that the magnitude of the increase from the Base condition is generally much less than 8 percent for all plans over the course of a high flow year with Plan 1 generating the greatest reduction in shoaling, especially along Atkinson Island. As noted in previous research, a lower flow year will generate much less shoaling in the channel, so the effects due to these plan conditions will likely be much less as well.

5 PA 14 Extension Results

The two extensions of PA 14 were modeled for hydrodynamics, vessel effects, and sediment transport. The results of these simulations were compared to the base condition, the 45- x 530-ft ship channel configuration. As in the previous chapter, the extension plans were analyzed for changes in flow conditions and sediment changes in the vicinity of the modifications. The figures to follow will coincide with the time stamps of those shown previously, so the base condition figures will not be repeated.

The velocity patterns for these plans during a high flow event at hour 2639.5 are shown in Figures 37 and 38. This is a time of high ebb directed flow. The velocity magnitudes are contoured such that blue areas are 0 ft/s and red areas are 1 ft/s. The base condition is found in Figure 9. Extension 1 increases the velocity along the southern side of the Bayport Channel while this area in extension 2 is very similar to the base condition. The flows moving from the channel toward Trinity Bay along the southern tip of PA 14 are affected by the extension distance. High velocity areas extend along the channel side of the placement area until they reach the end and flow can spread out. Extension 2 produces a larger area of higher velocities at its southern tip than does Extension 1 or the base condition. At hour 7749.5 the high ebb flow is ending and the flow direction is about to change. Figures 39 and 40 show the velocity magnitudes and directions for each extension at this time. The base condition is shown in Figure 13. The higher flows along the east side of the placement area are extended along the island and therefore the range over which these flows extend is increased. The low flow area to the southwest side of the island is reduced with the extension increases. Figures 41 and 42 show the velocity pattern at hour 10709.5 which is during a flood flow situation with large upstream directed flows in the channel. At this time the base condition (Figure 17) shows an area of high flows south of PA 14. As PA 14 is extended, this high flow area is encroached upon and the area of high flows enlarges due to the natural flow pattern around the island and the added influence of the obstruction. The location of this high flow area does not really change, simply its size and the magnitudes of the flows it includes. The area of higher flows on the western side of the channel south of Bayport is also extended slightly due to the change in flows on the eastern side of the ship channel.

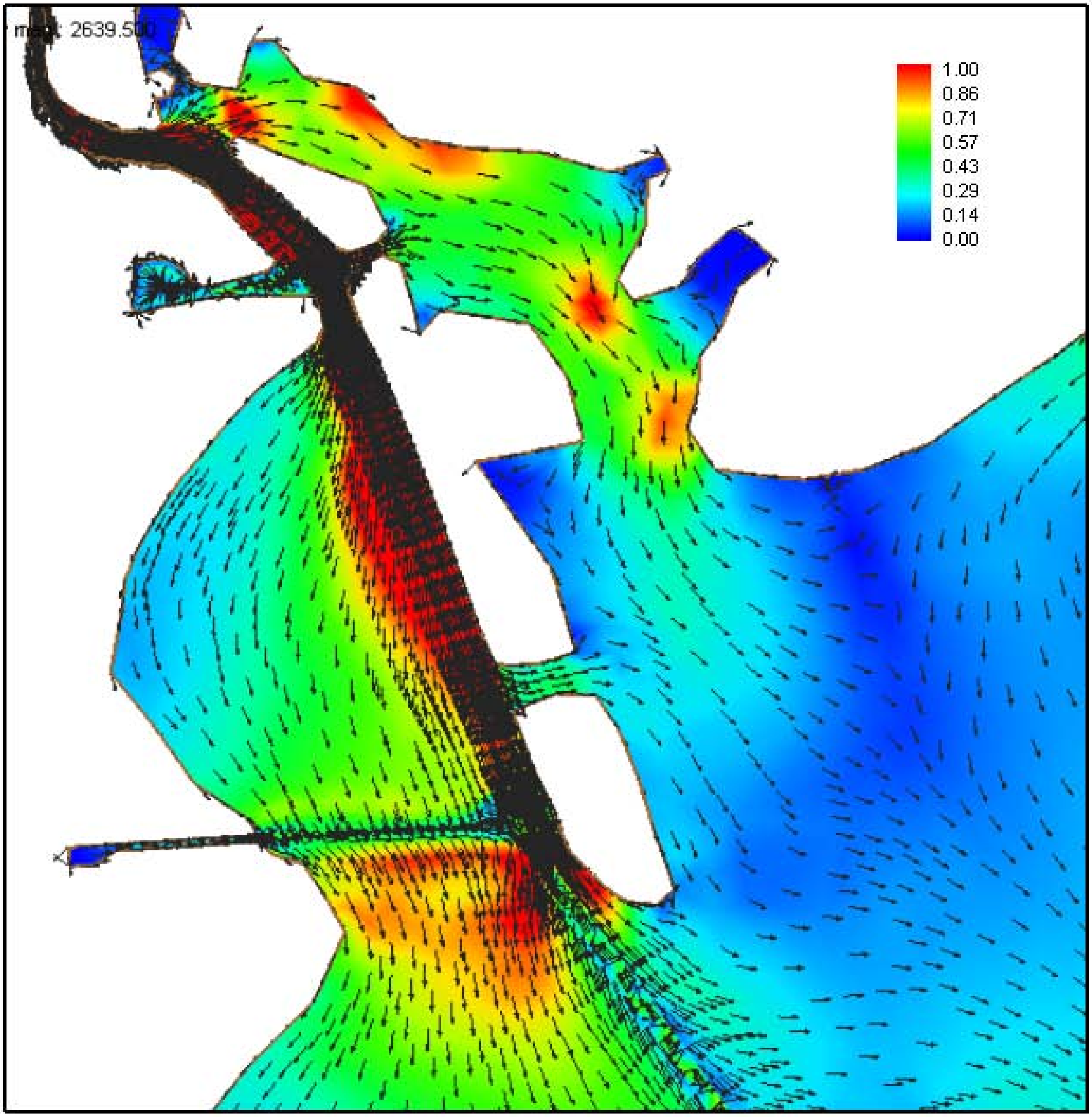

Figure 37. Velocity magnitude and direction at hour 2639.5 during high flow event for extension 1 (ft/s).

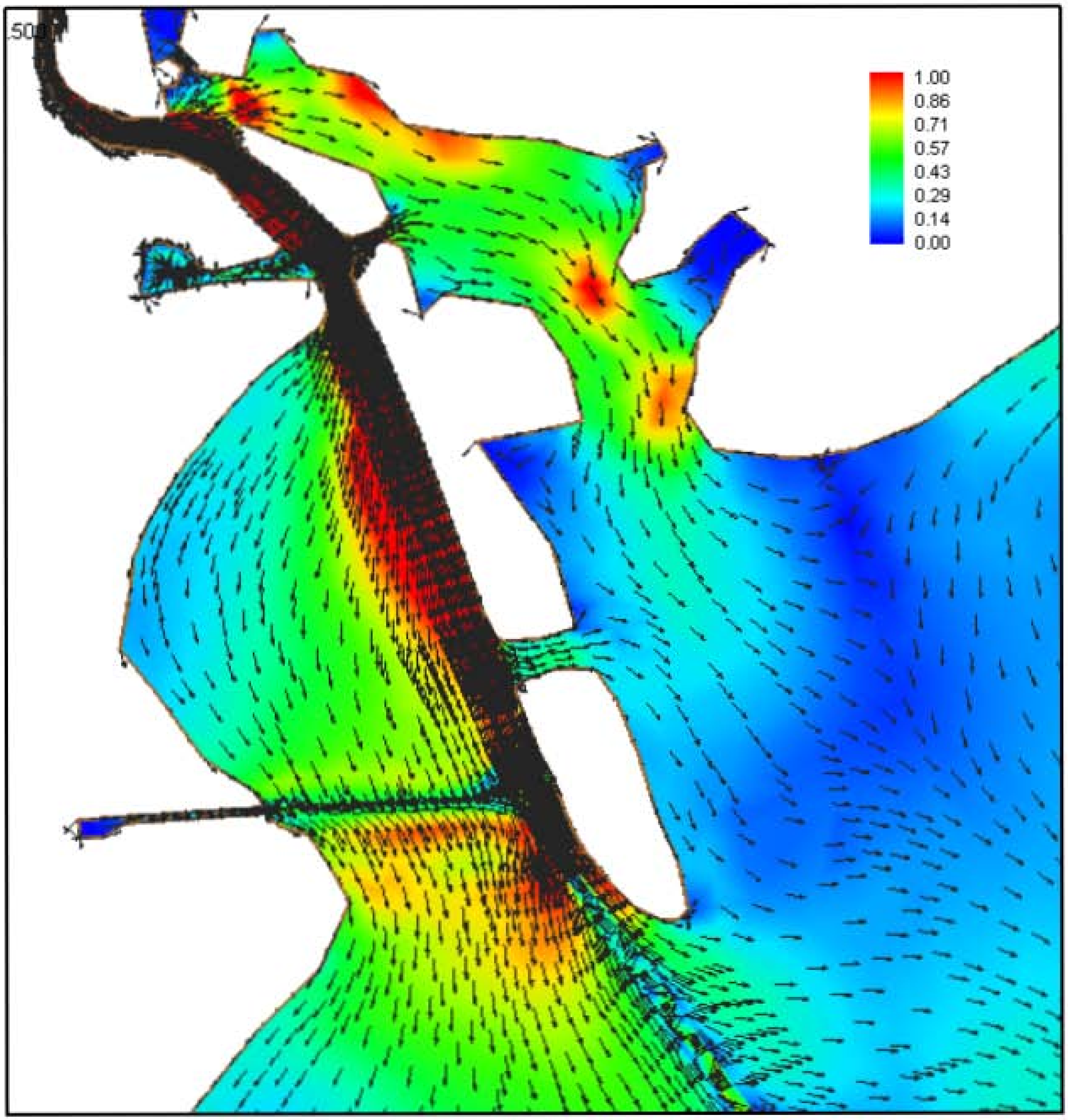

Figure 38. Velocity magnitude and direction at hour 2639.5 during high flow event for extension 2 (ft/s).

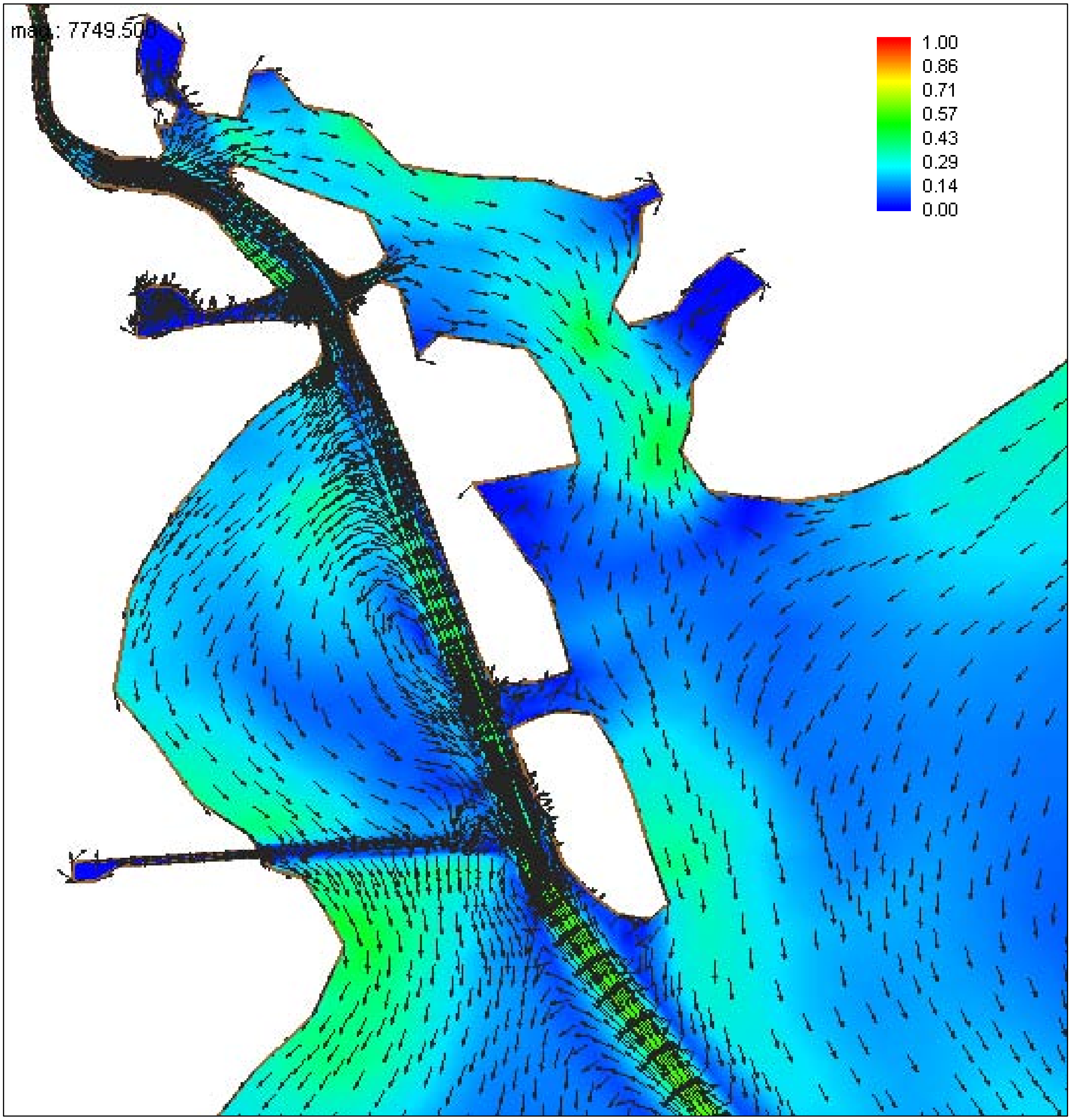

Figure 39. Velocity magnitude and direction at hour 7749.5 for extension 1 (ft/s).

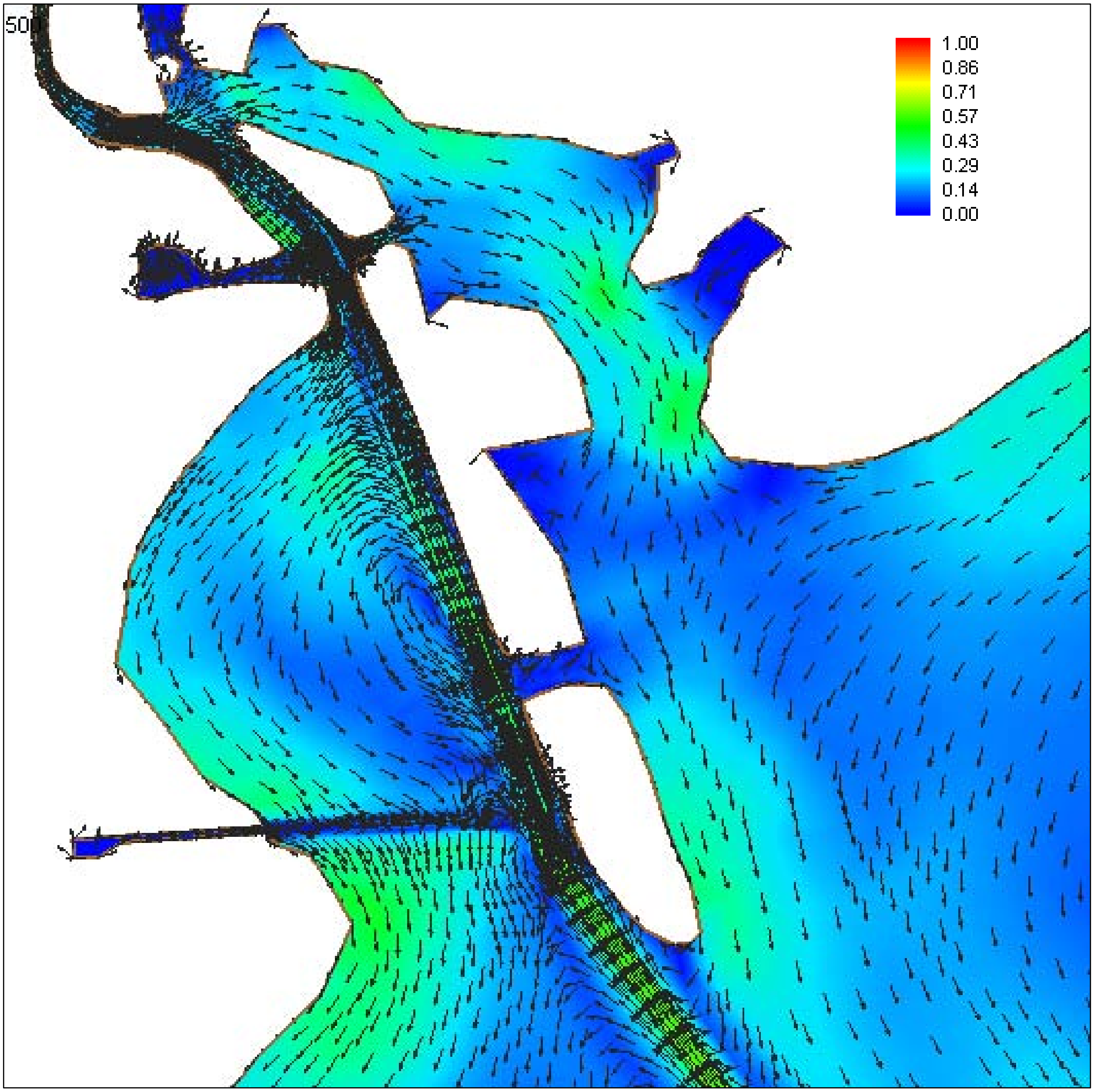

Figure 40. Velocity magnitude and direction at hour 7749.5 for extension 2 (ft/s).

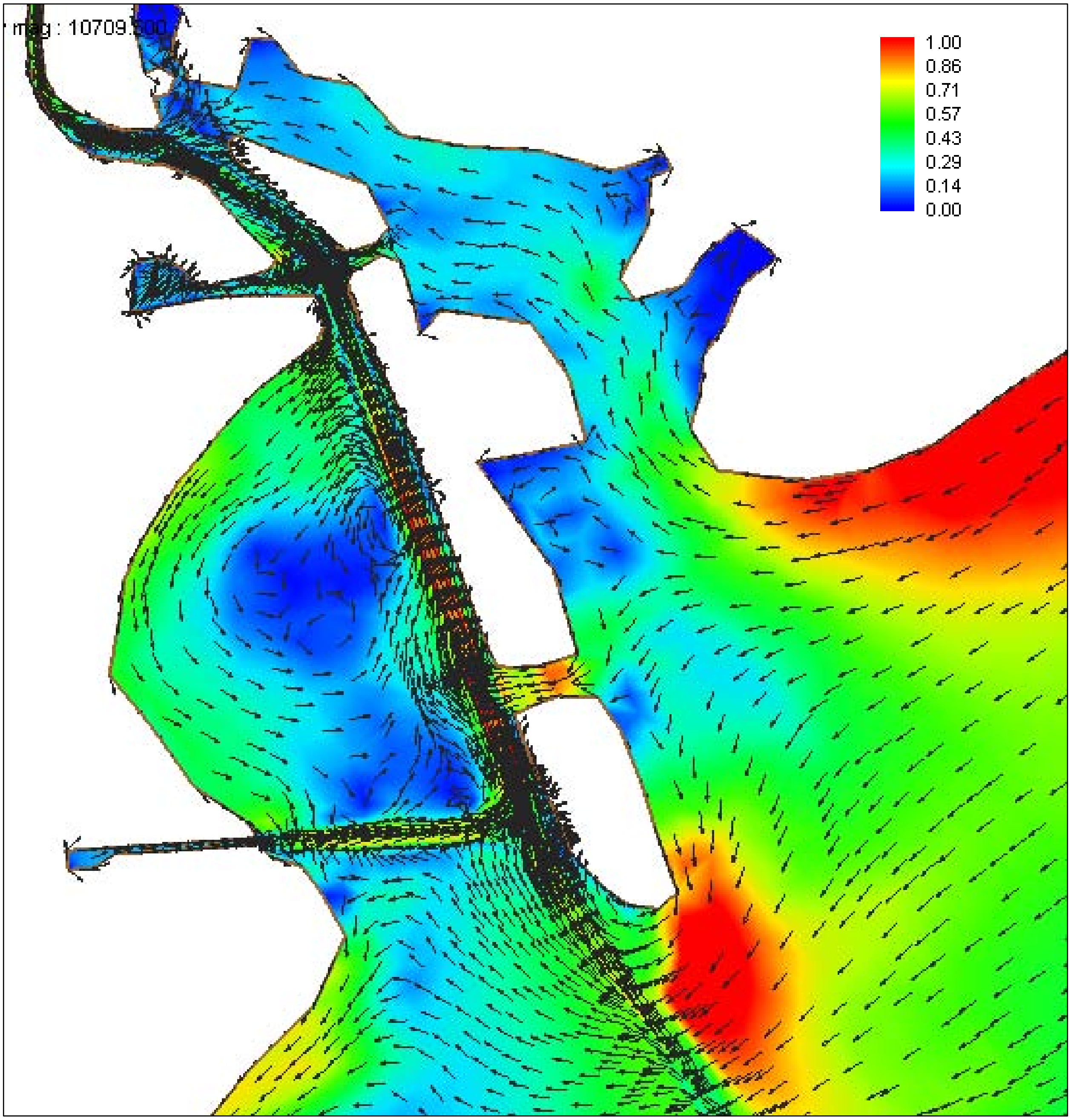

Figure 41. Velocity magnitude and direction at hour 10709.5 for extension 1 (ft/s).

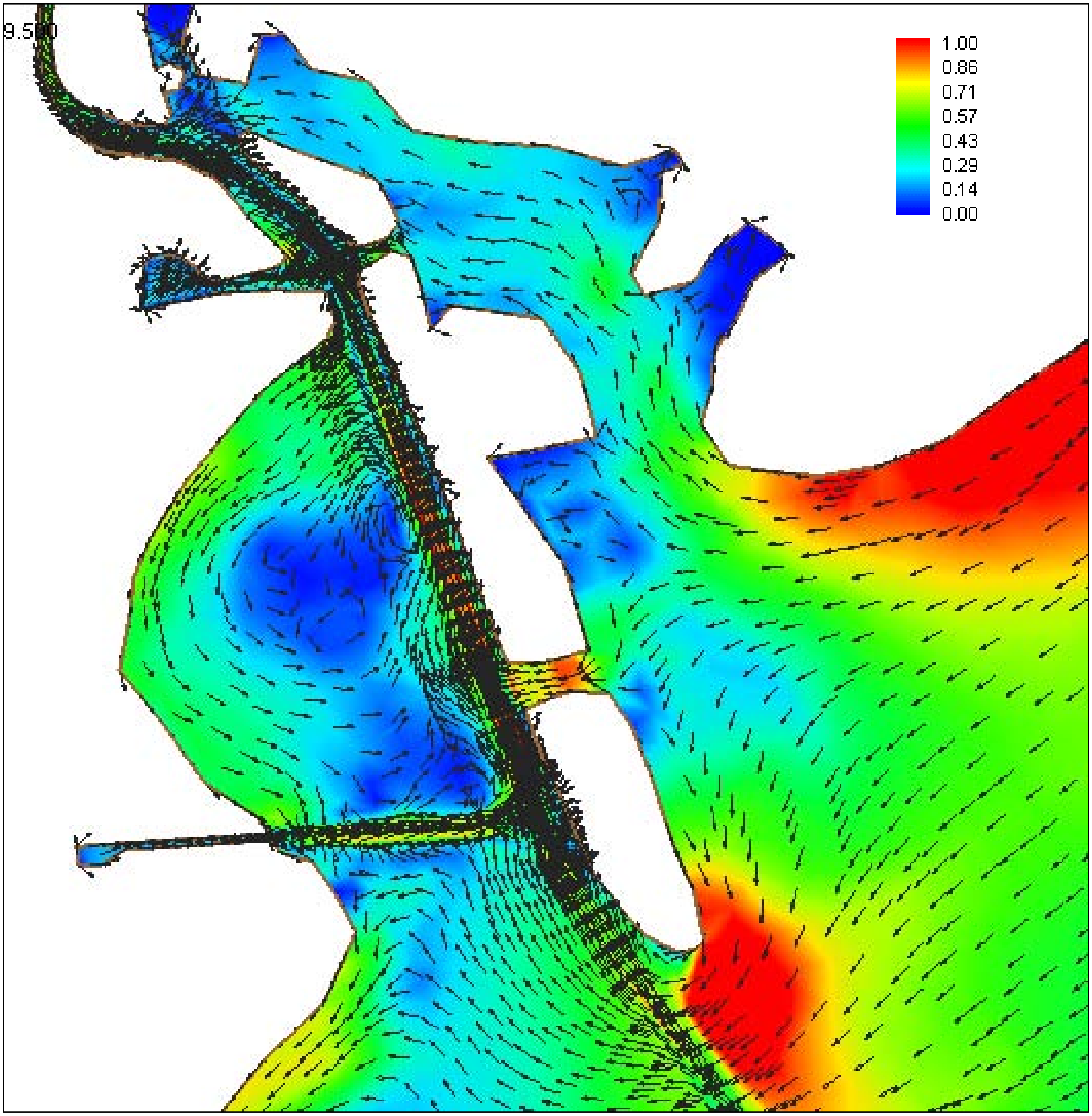

Figure 42. Velocity magnitude and direction at hour 10709.5 for extension 2 (ft/s).

The bed displacement results at six and twelve months for the two extensions of PA 14 are shown in Figures 43 - 46. Figures 47 - 49 show the twelve month displacement on a smaller contour scale. Again, the base condition results can be found in the previous chapter. The difference in the magnitude of the bed displacement from the base condition for Extension 1 at six and twelve months is shown in Figures 50 - 51. The same results for Extension 2 are shown in Figures 52 - 53. These figures are all contoured between -0.01 m and +0.01 m unless noted otherwise.

At six months, there is already more erosion behind PA 14 for each extension. The deposition just east of this area of erosion extends southward along with the extension of the placement area. However, the deposition at the south end of PA 14 in the base condition is reduced with both extensions. Extension 1 appears to reduce the deposition to the southwest of the Bayport Flare, as compared to the base, while Extension 2 shows less of a reduction at this location.

The results at twelve months are shown for two different contour intervals. As with the six month results, the erosion on the east side of PA 14 is increased with the extensions and the deposition at the southern tip of the placement area is reduced. When contoured on a smaller scale, changes in the deposition in the shallower regions become more visible. The deposition in western Trinity Bay north of the Bayport Channel is reduced slightly from the base condition with both extensions, but Extension 1 shows a larger reduction. This behavior is also seen south of the Bayport Flare. Extension 1 and Extension 2 both show a reduction in shoaling, yet the reduction from Extension 1 is more widespread.

The difference of the extension plans from the base condition show that the largest change is on the eastern side of the placement area and the spatial coverage of these differences is tied to the size of the extension. In other words, the differences in Extension 1 from the base cover a smaller area than do those from Extension 2. There are also smaller differences in the ship channel just downstream of the placement area and on the sideslopes of the Bayport Channel, most noticeable in Extension 2. Figures 54-56 are displacement contours that allow for a closer inspection of the Bayport Flare and channel. These figures are contoured between 0.01 and 0.04 m and show results at the end of the year-long simulation. Extension 1 produces a small reduction in shoaling in the Bayport Flare where it intersects the Houston Ship Channel and in the Bayport Channel. Extension 2 shows a much lower reduction in shoaling in the flare and channel. This plan extension also indicates more deposition in the Houston Ship Channel at the southern end of the placement area whereas Extension 1 showed no noticeable changes in the ship channel in this area.

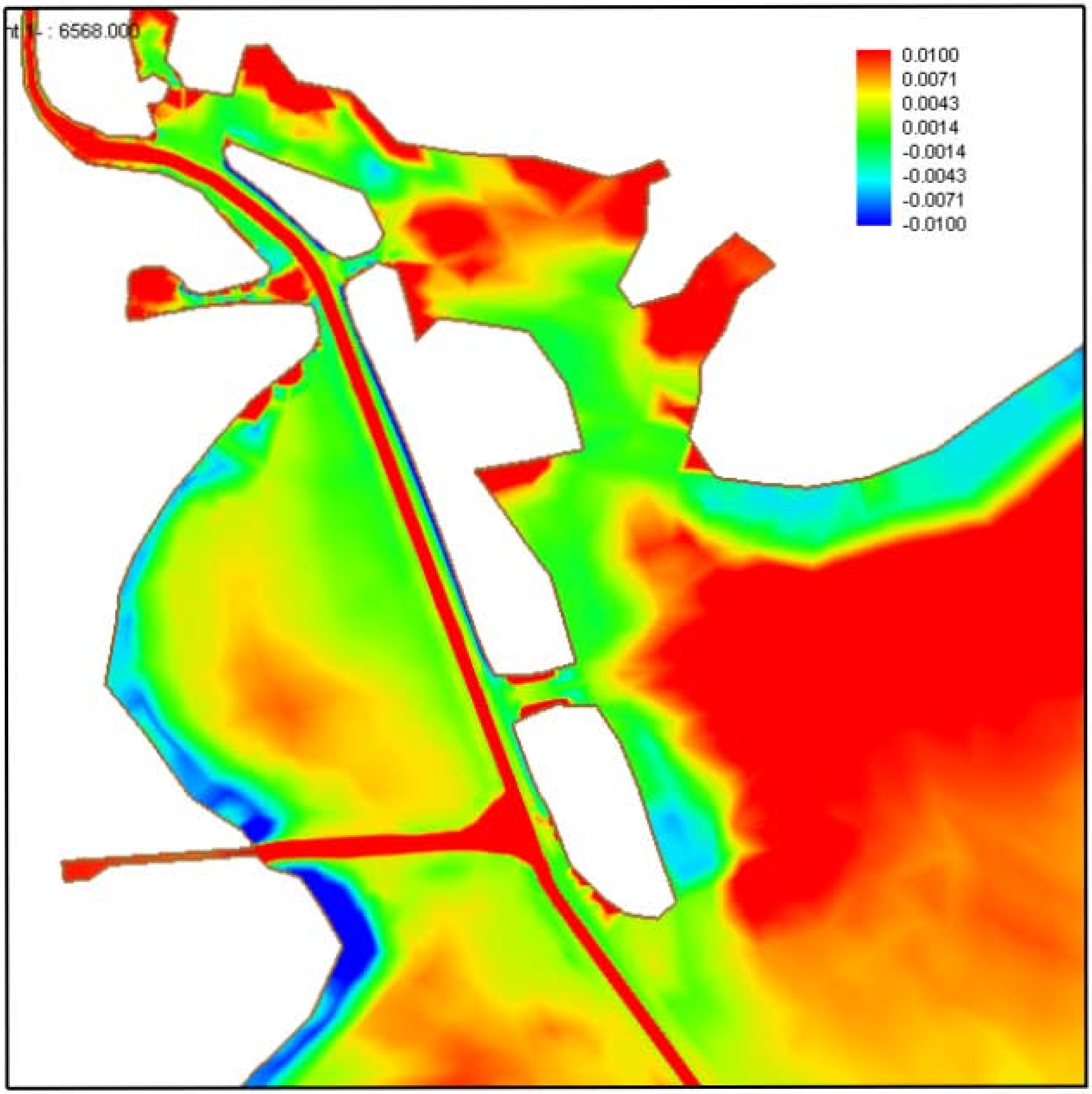

Figure 43. Bed displacement for Extension 1 at six months (m).

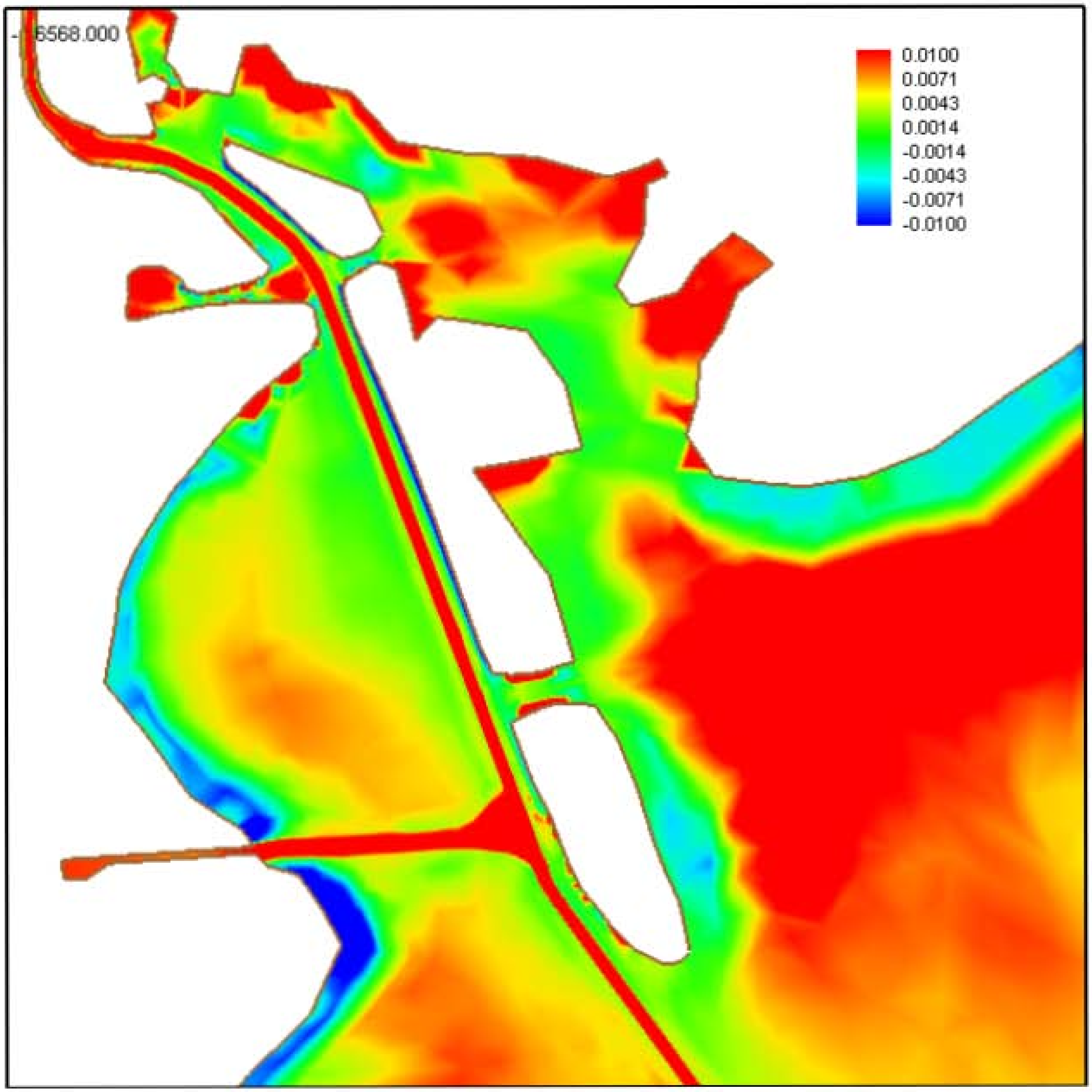

Figure 44. Bed displacement for Extension 2 at six months (m).

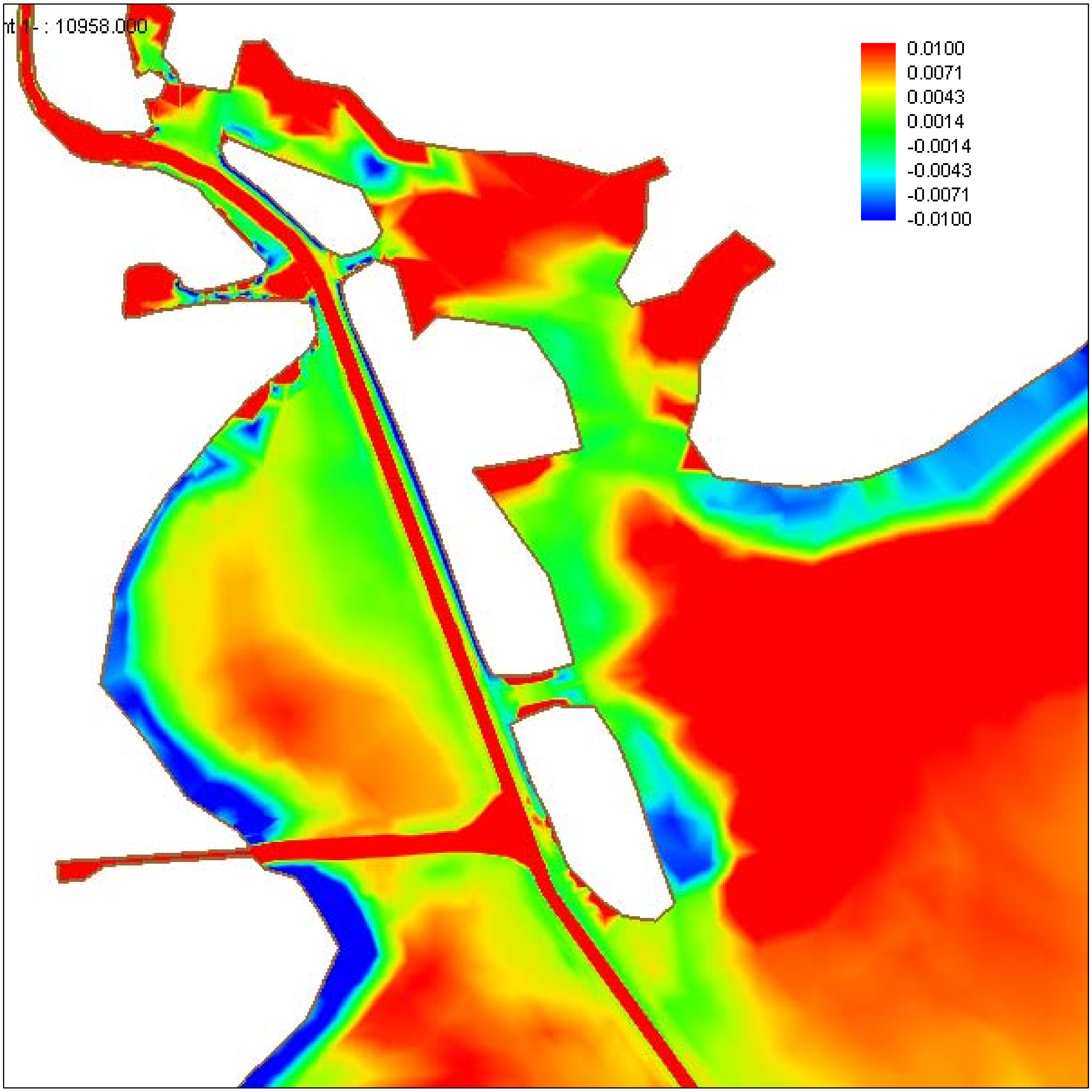

Figure 45. Bed displacement for Extension 1 at twelve months (m).

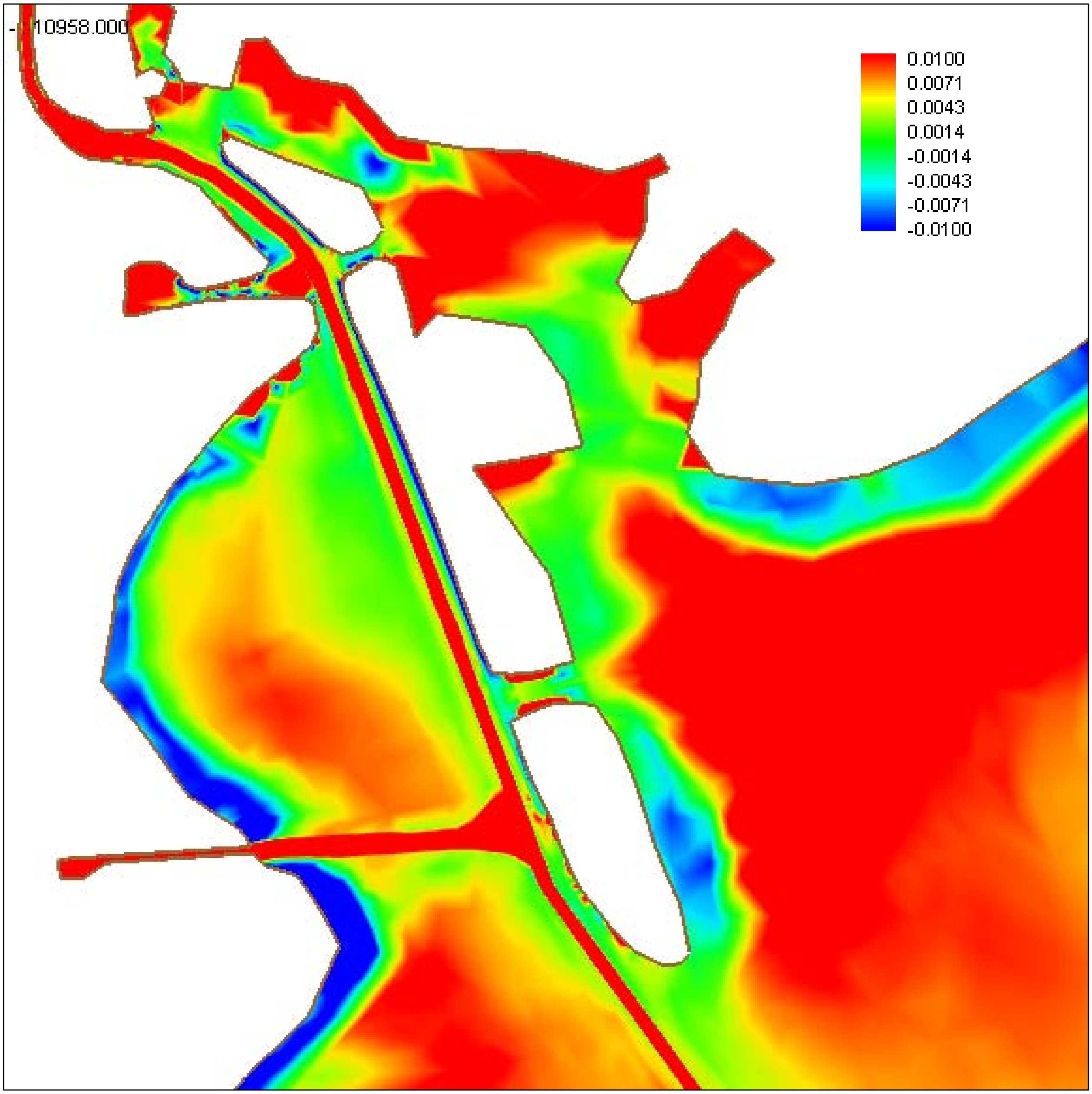

Figure 46. Bed displacement for Extension 2 at twelve months (m).

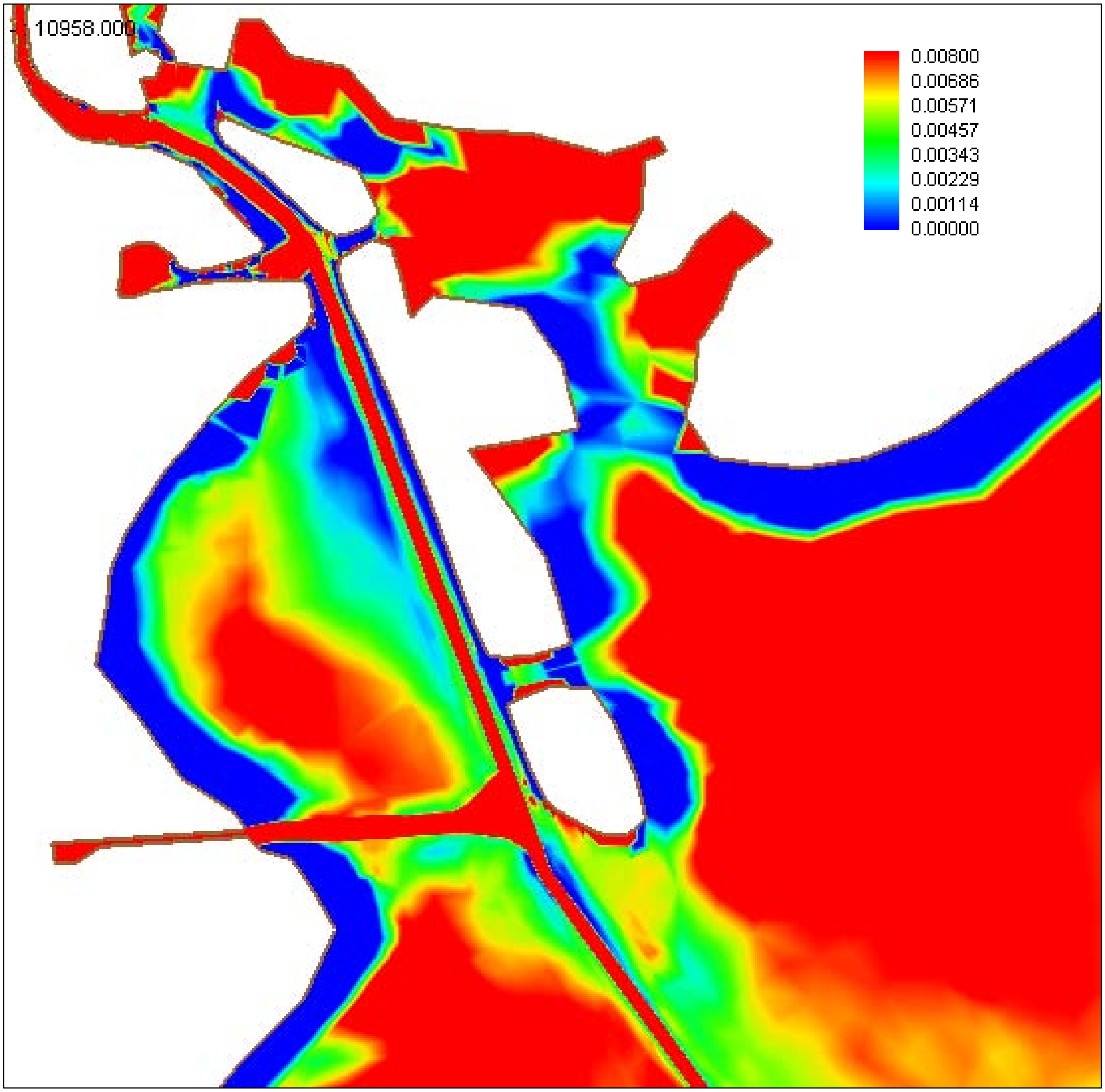

Figure 47. Bed Displacement for Base at 12 months (m).

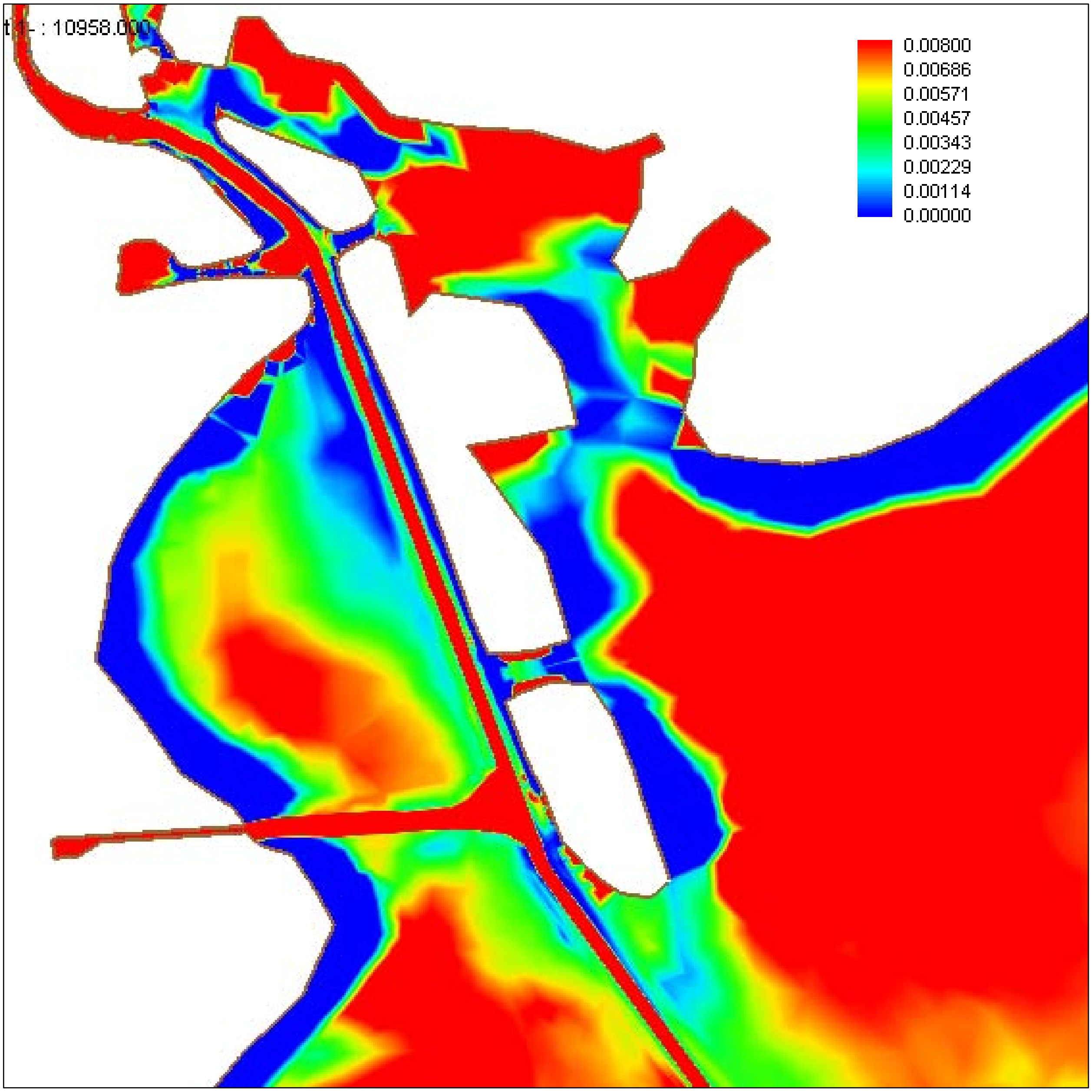

Figure 48. Bed Displacement for Extension 1 at 12 months (m).

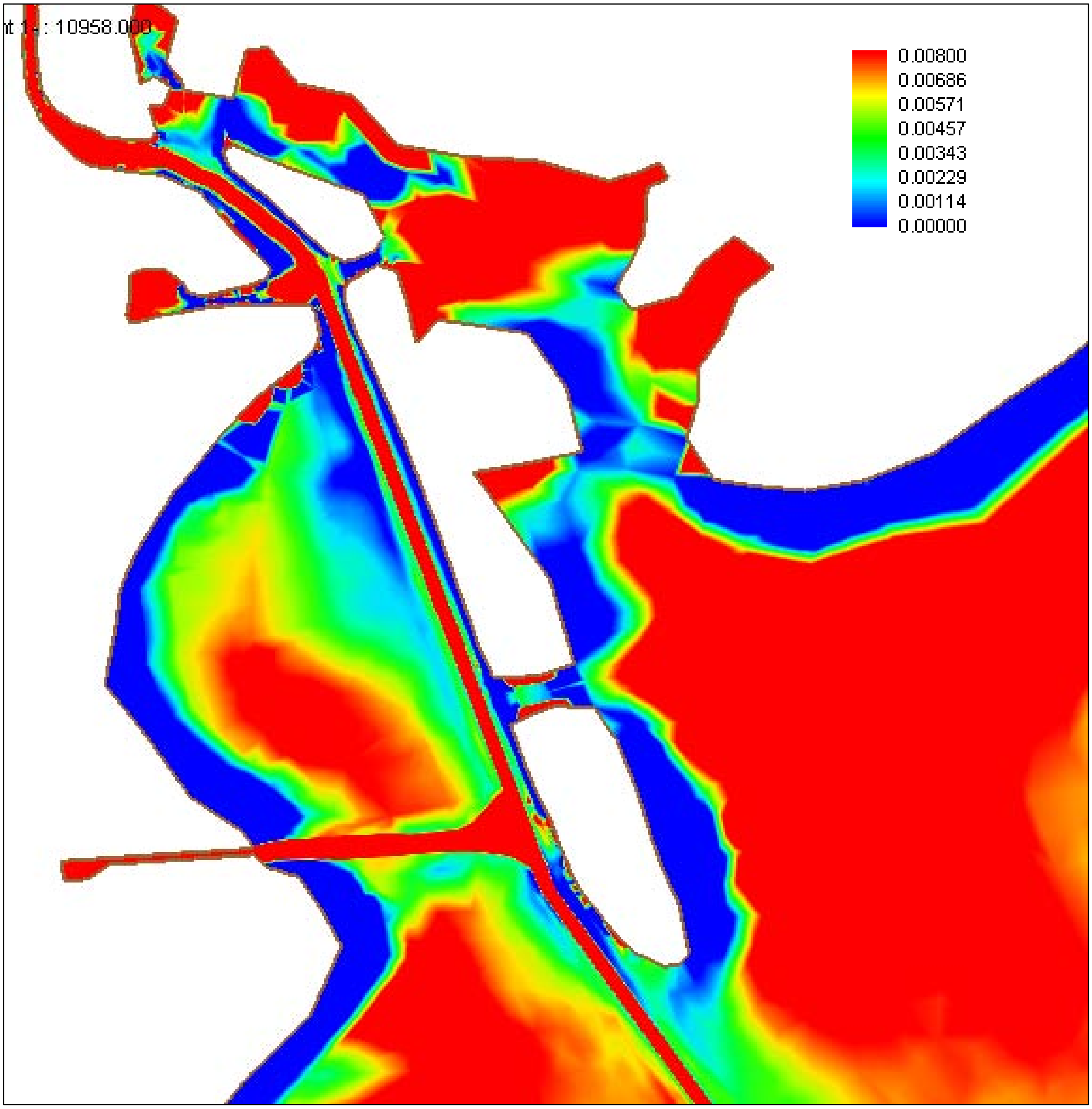

Figure 49. Bed Displacement for Extension 2 at 12 months (m).

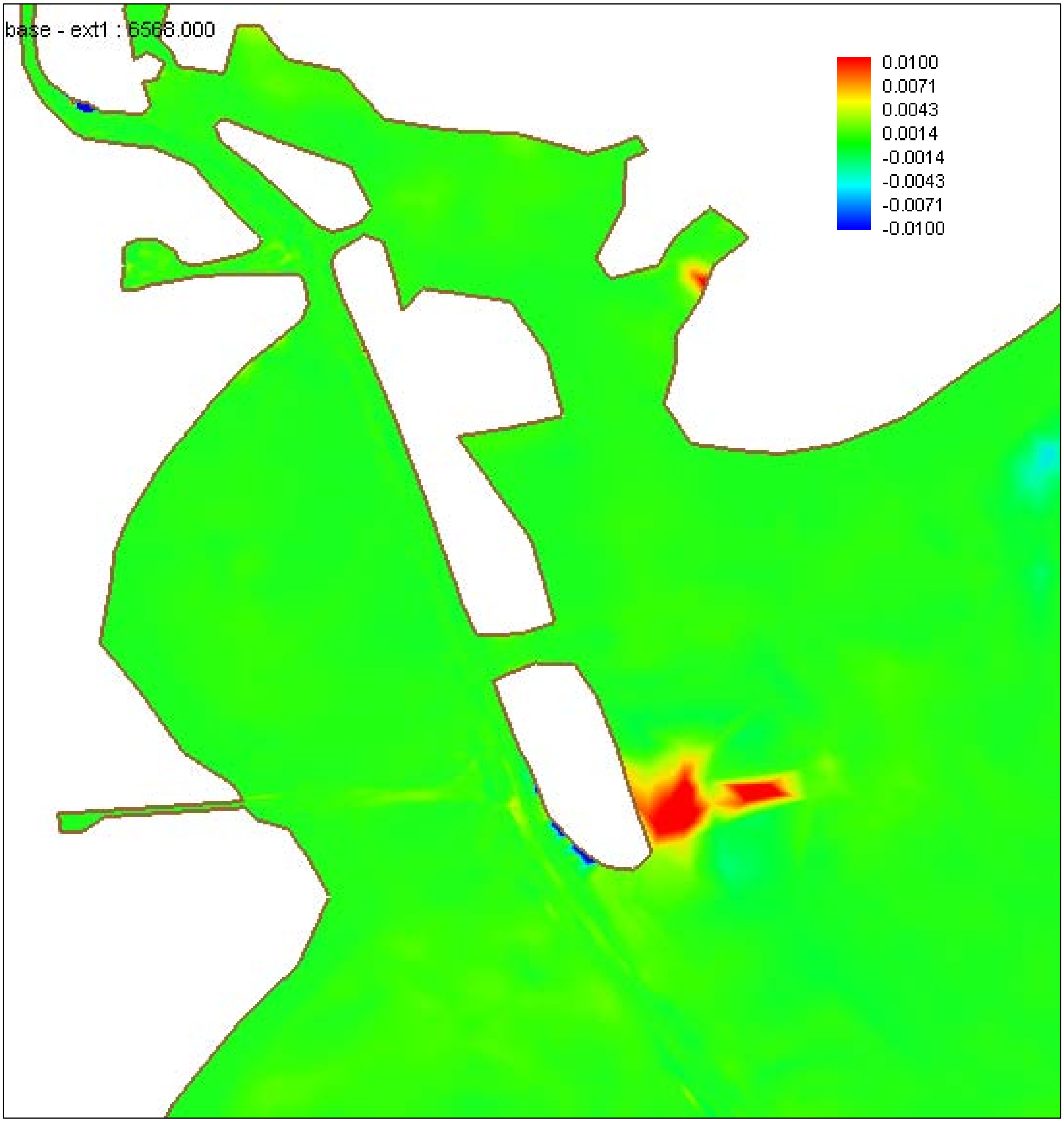

Figure 50. Difference in bed displacement of Extension 1 from Base at six months (Base – Extension 1).

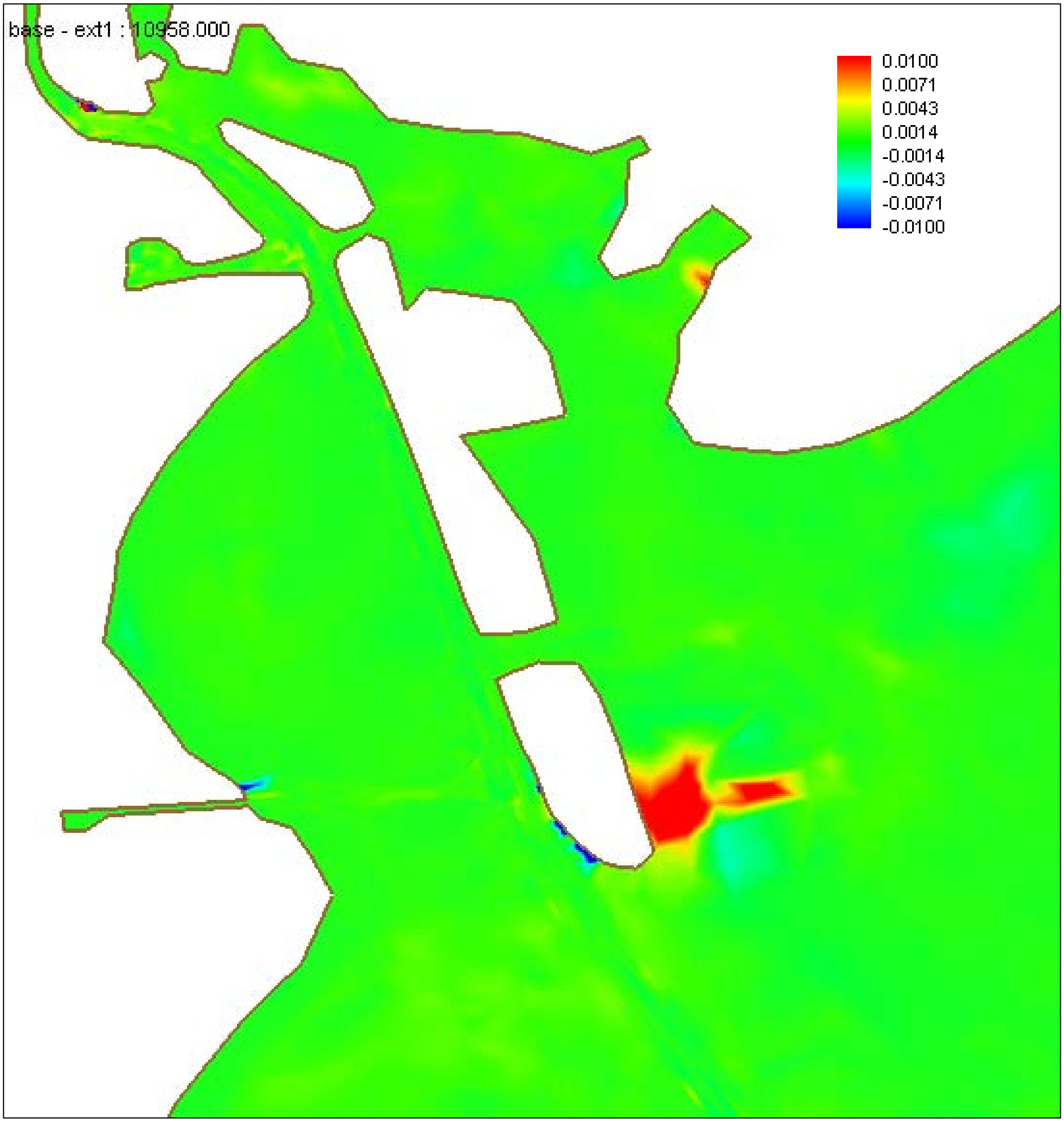

Figure 51. Difference in bed displacement of Extension 1 from Base at twelve months (Base – Extension 1).

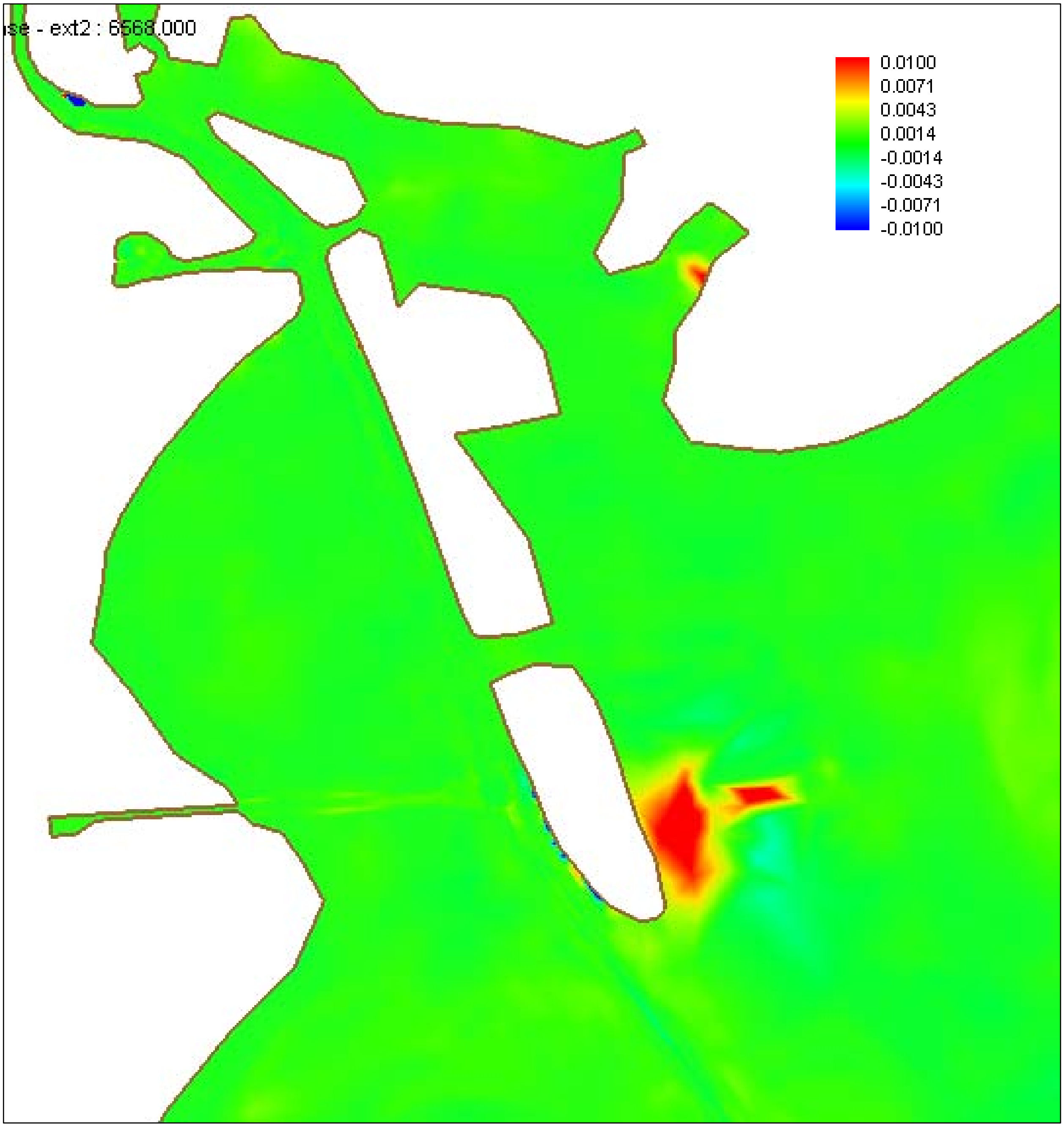

Figure 52. Difference in bed displacement of Extension 2 from Base at six months (Base – Extension 2).

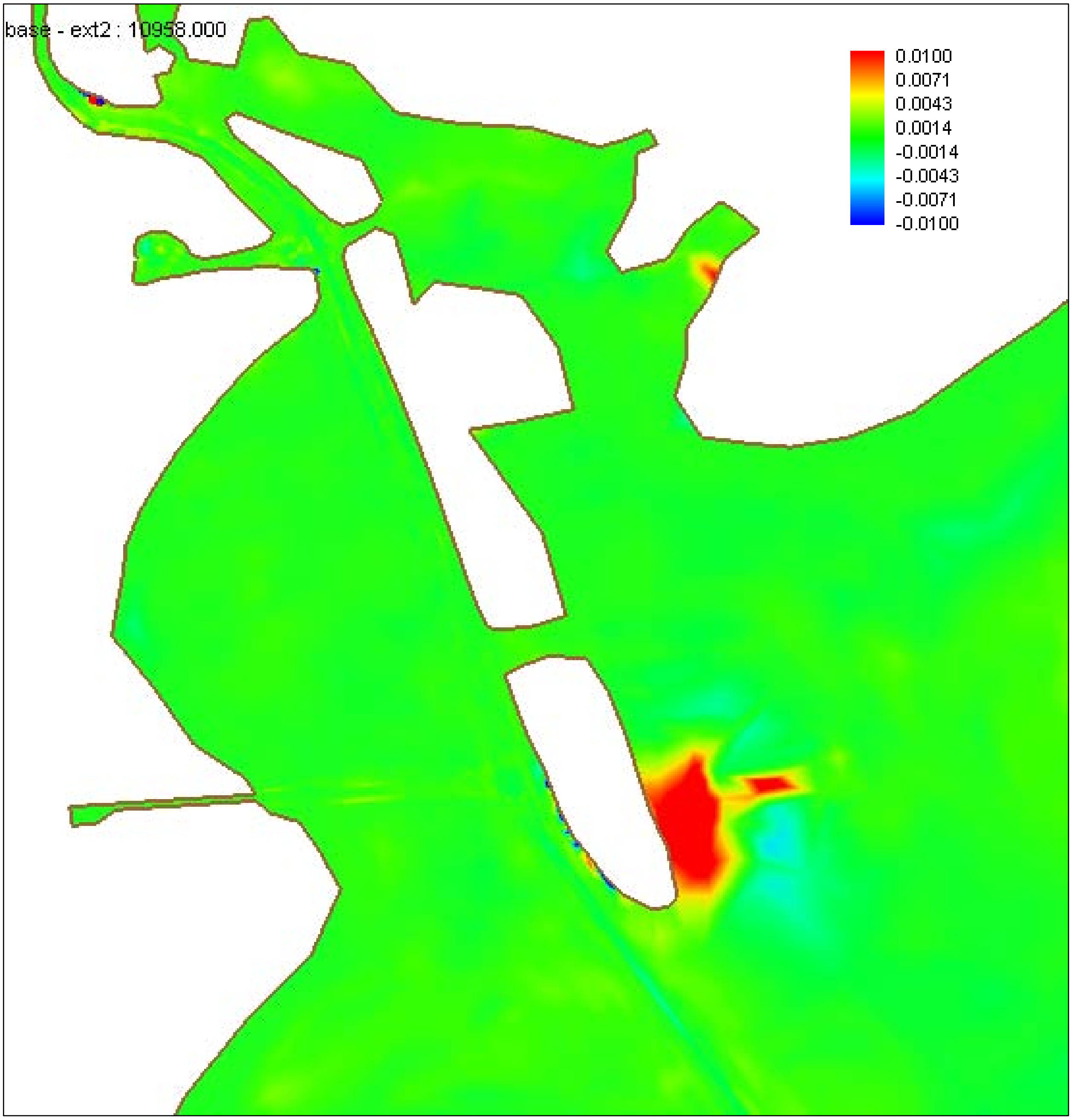

Figure 53. Difference in bed displacement of Extension 2 from Base at twelve months (Base – Extension 2).

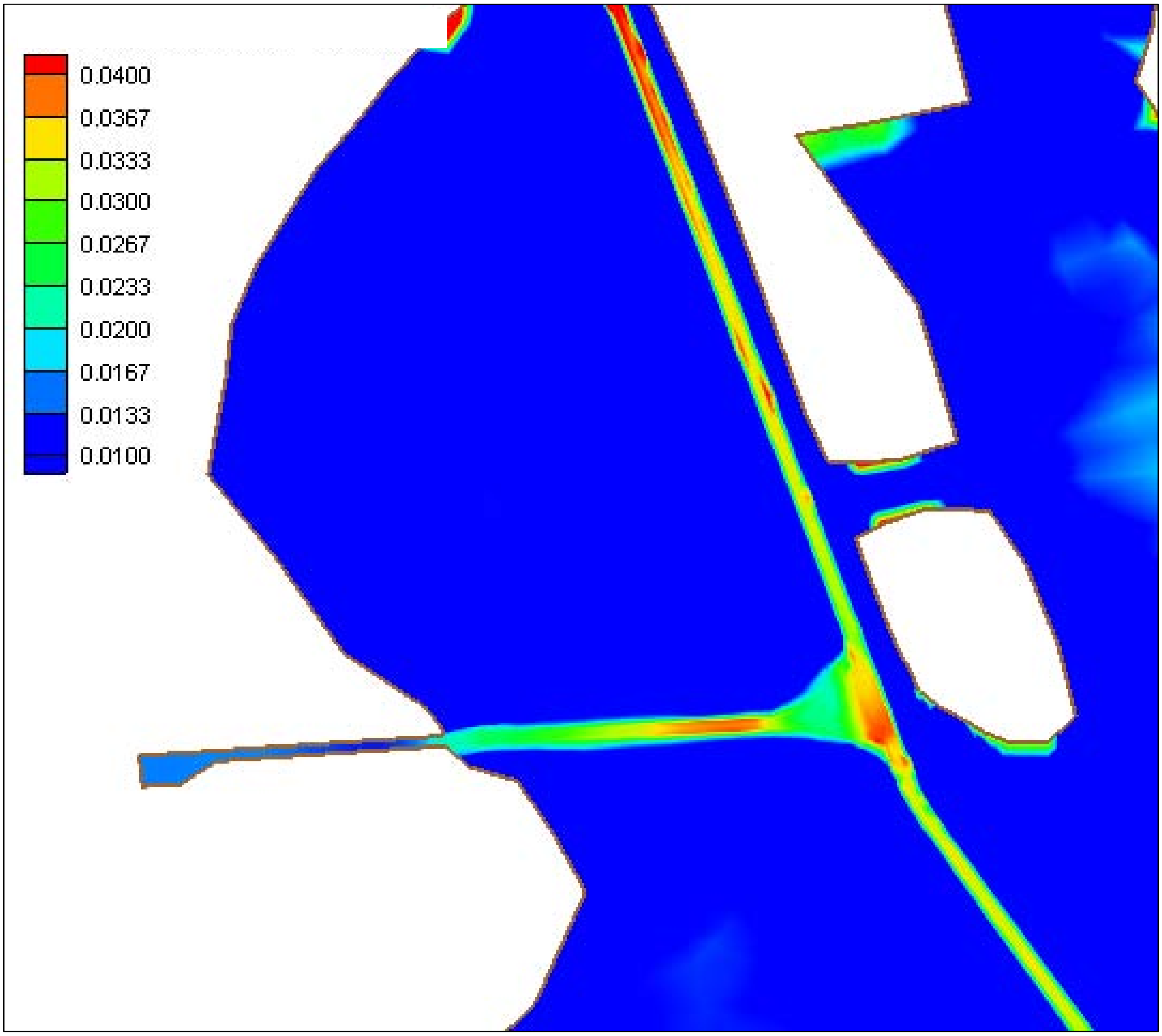

Figure 54. Bed displacement for Base at 12 months (m).

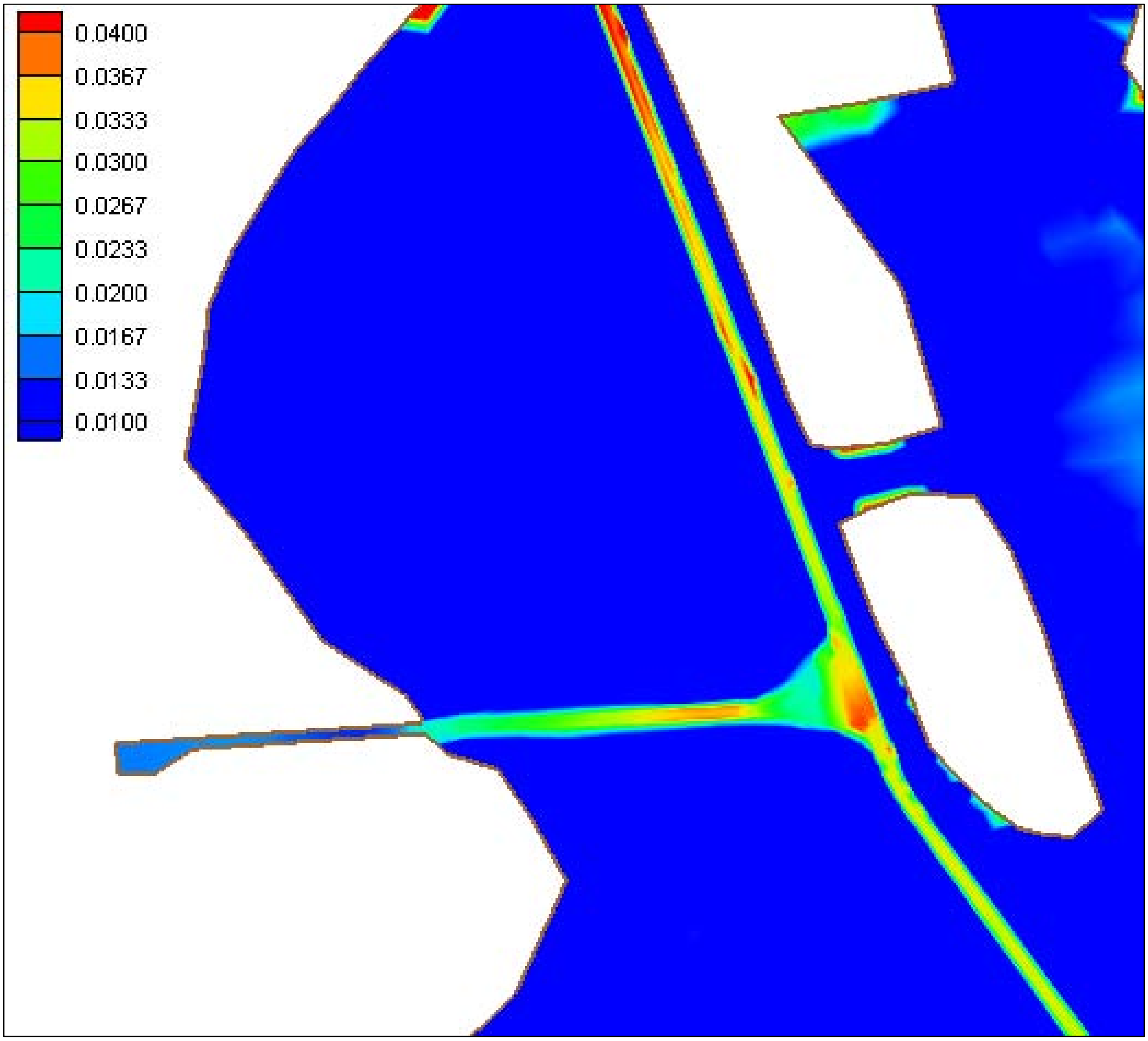

Figure 55. Bed displacement for Extension 1 at 12 months (m).

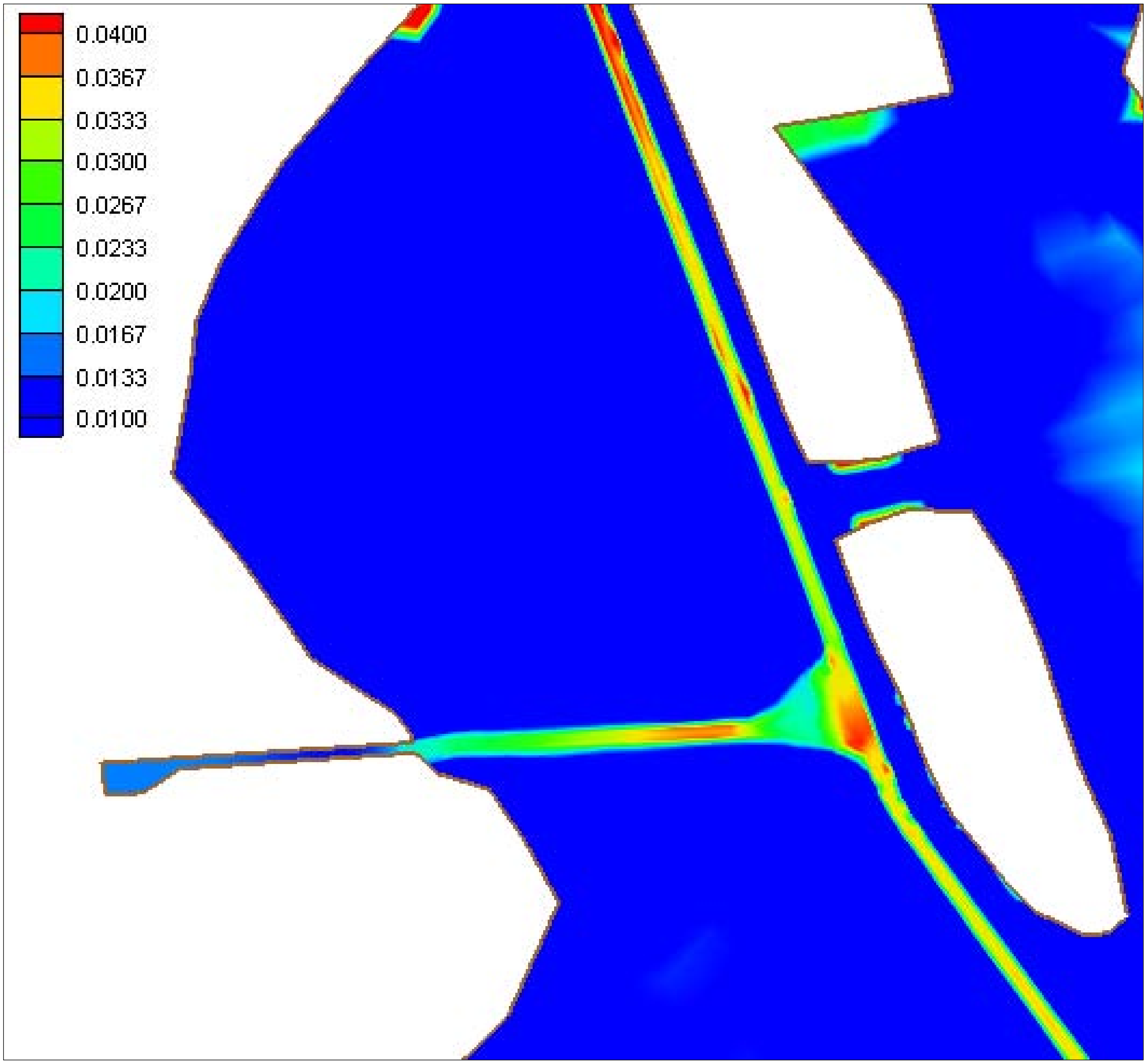

Figure 56. Bed displacement for Extension 2 at 12 months (m).

Figures 57 and 58 focus specifically on the Houston Ship Channel. The displacement along the channel bed from Morgan's Point to Bolivar Roads for the base condition and both extensions is given in Figure 57. The percentage difference in the bed displacement of each extension from the base is shown in Figure 58. The changes upstream of the Bayport Flare are minimal indicating that by extending PA 14, the shoaling along Atkinson Island will not be greatly affected. However, the changes that do occur generally result in more shoaling. At the location of the Bayport Flare and southward along the extended PA 14, there is an increase in shoaling along the channel center. Although Extension 2 provides a small decrease in shoaling along Atkinson Island, it produces as much as 14 percent increase in shoaling downstream near the Mid Bay Marsh site (see Figure 6).

Generally, the two extensions result in about the same change except in the area just downstream of PA14, as expected since this is the location of the geometry changes. Extension 1 does reduce the shoaling some in this area but it is only by approximately 5 percent. Based on these results, Extension 2 is too large and begins to trap sediment on the channel side of the placement area, which has a larger overall effect than it's ability to prevent sediment from passing around the east side of PA 14 into the channel. The likely reason for the increase in sediment in the area of the Red Fish Reef and further downstream is that the sediment that is no longer allowed to pass into the channel around PA 14 moves downstream away from the channel and then enters further downstream where it then falls to the channel bed.

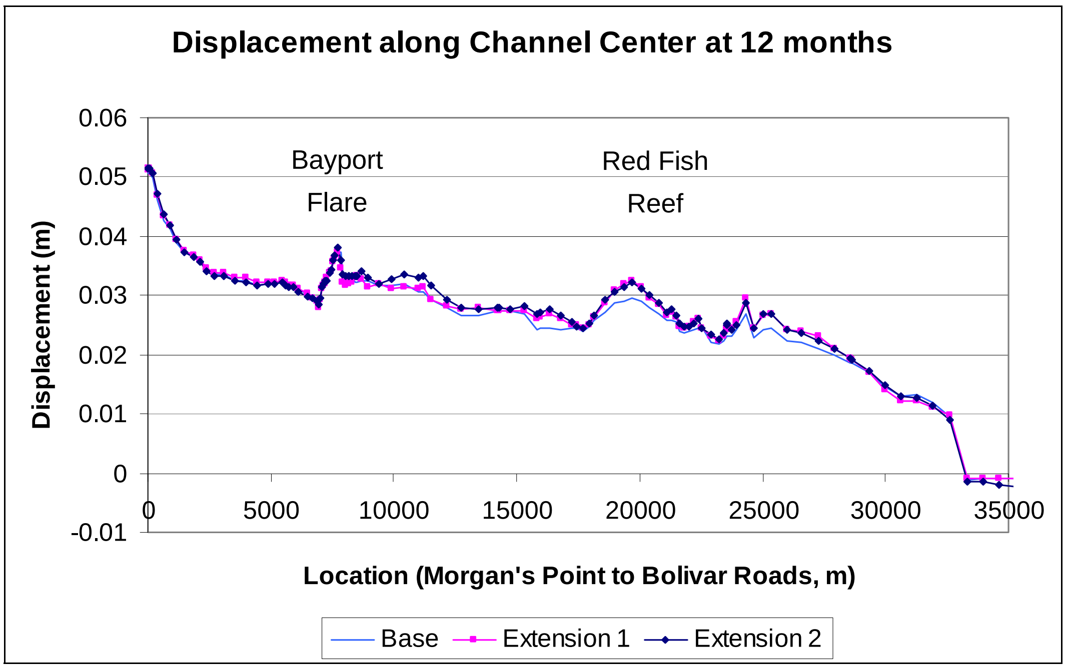

Figure 57. Channel bed displacement after 1-year for Base and two extensions.

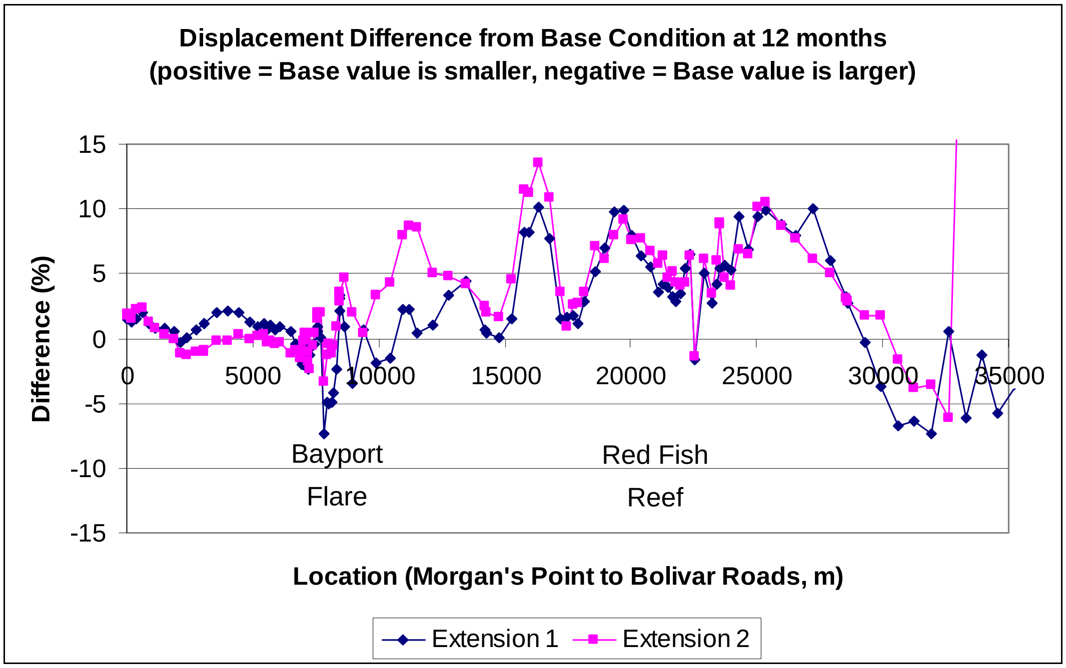

Figure 58. Percentage difference in channel bed displacement from Base for two extensions.

6 Conclusions

These base/plan comparisons of changes in hydrodynamics and sediment transport were performed using a validated sediment model that includes the effects of the large number of vessels traveling the Houston Ship Channel daily. Model validation focused on the area upstream of Red Fish Reef, so results downstream of this area should be considered with caution. It is also important to note that the validated model performed well for shoaling distribution in the channel and surrounding shallows but the rate of shoaling was underpredicted, especially in the ship channel. The model was only able to account for 20 percent of the deposition rate experienced in the field (Tate et al. 2008). The model's low prediction of the shoaling volume may be due to several factors requiring more research and analysis, including the possibility of fluid mud, the application of suspended sediment loads, and the fate of dredged material.

The simulations analyzed changes over one year of generally high flow conditions. Two sets of alternatives were tested: 1) modifications to the placement areas at Atkinson Island and the gap between PA 14 and PA 15 and 2) an optimum extension distance for PA 14.

The changes produced by the plan conditions are primarily found on the eastern side of Atkinson Island; however, they also generate changes in the shoaling seen in the channel near the location of the gap between PA 14 and PA 15 and southward. Although the changes in hydrodynamics due to these plan conditions are dominated by increased velocities in some areas, the change in the magnitudes is fairly small and in most instances will not generate more erosion of bed material. However, the changes in the flow patterns do produce new, or move, areas of deposition due to the settling nature of the particles in suspension. The extension of PA 14 has less of an effect along Atkinson Island but generates a larger increase in shoaling downstream in the Houston Ship Channel. Since these simulations were performed using a high flow water year as the flow boundary condition, these sedimentation results are on the high side of what will happen within the system. Overall, these plan conditions generate small changes in the shoaling in the Houston Ship Channel, less than an 8 percent increase in displacement on average, and the significant effects due to the changes remain in the vicinity of the modifications.

Plan 1 does generate a reduction in shoaling along Atkinson Island as well as the lowest overall increases in deposition downstream within the channel. The extension analysis indicates increases in deposition within the channel due to trapped sediment, as opposed to preventing suspended sediment from entering the ship channel just south of Atkinson Island (PA 14). Given the results of these simulations, extending PA 14 will not reduce the shoaling in the ship channel and will likely produce negative effects further downstream. Plans 1, 2, and 3 also do not provide great improvements to the shoaling in the channel. Since the marsh sites, M5 – M8, are currently being constructed, the Plan 1 condition is not an available option. Considering this fact and based on the model simulation results, closing the gap between PA 14 and PA 15 will provide a lower increase in shoaling along Atkinson Island as compared to leaving the gap open as well as prevent an increase in deposition in the ship channel further downstream. The gap was modeled as fully open in the existing plan runs. However, it is not known just how much the gap is truly open in the prototype. Thus, the anticipated benefits from closing this gap may have essentially already been realized if the deposited sediment has remained in the gap. This plan does generate changes in the sedimentation patterns on the east side of Atkinson Island but these changes are not large or wide spread and the impact of these changes is not critical to navigation of the Houston Ship Channel.

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14. ABSTRACT

This report documents the results of several plan scenarios on the sedimentation behavior in the Houston-Galveston Ship Channel area. The U.S. Army Engineer District, Galveston, recently enlarged the Houston Ship Channel in depth and width. Preliminary evaluations of the enlarged channel indicate a higher than anticipated rate of deposition in the channel reach near Atkinson Island. A Coastal and Hydraulics Laboratory investigation (Tate and Berger 2006) was charged with determining if this higher deposition rate is a permanent feature or only a temporary issue. A preliminary study focused on the change in currents, as determined by the model, from the pre-enlarged channel to the new configuration and a sediment tracer analysis. The results of this study determined that the dredging should have been only about 20-30 percent higher than for the pre-enlarged channel. This implies that a large increase would be due to other considerations, such as dredged material resuspended from disposal areas and redepositing in the channel, channel dimension equilibration, or vessel impacts on the shoaling. This preliminary study used the sediment model in an unvalidated state for early results to aid planning. In addition to an unvalidated model, other limitations were that the sediment pathways and loadings were not modeled but assumed. A more general validated tool was needed to estimate the causes of the shoaling with the enlarged channel and suggest approaches to reduce the deposition rate. Knowing that there are many factors that contribute to sediment transport, the logical next step was to develop and validate the sediment model. With a validated sediment model, testing and decision making can be made while considering many factors simultaneously. In the validation process it was determined that vessel traffic was important in the deposition and resuspension of sediment. Vessel effects, therefore, are included in this model. The end result is a model that is capable of reproducing tides, circulation, salinity, and sediment transport in Galveston Bay. In addition to these properties, the model also includes the effects of vessel traffic on the sediment transport in the area (Tate et al. 2008). Now that the validated sediment model is available, plan simulations can be performed to analyze the effects of various changes within the system.

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